W & Z Physics at the Tevatron

Physics in Collision
Annecy : June 27 2007

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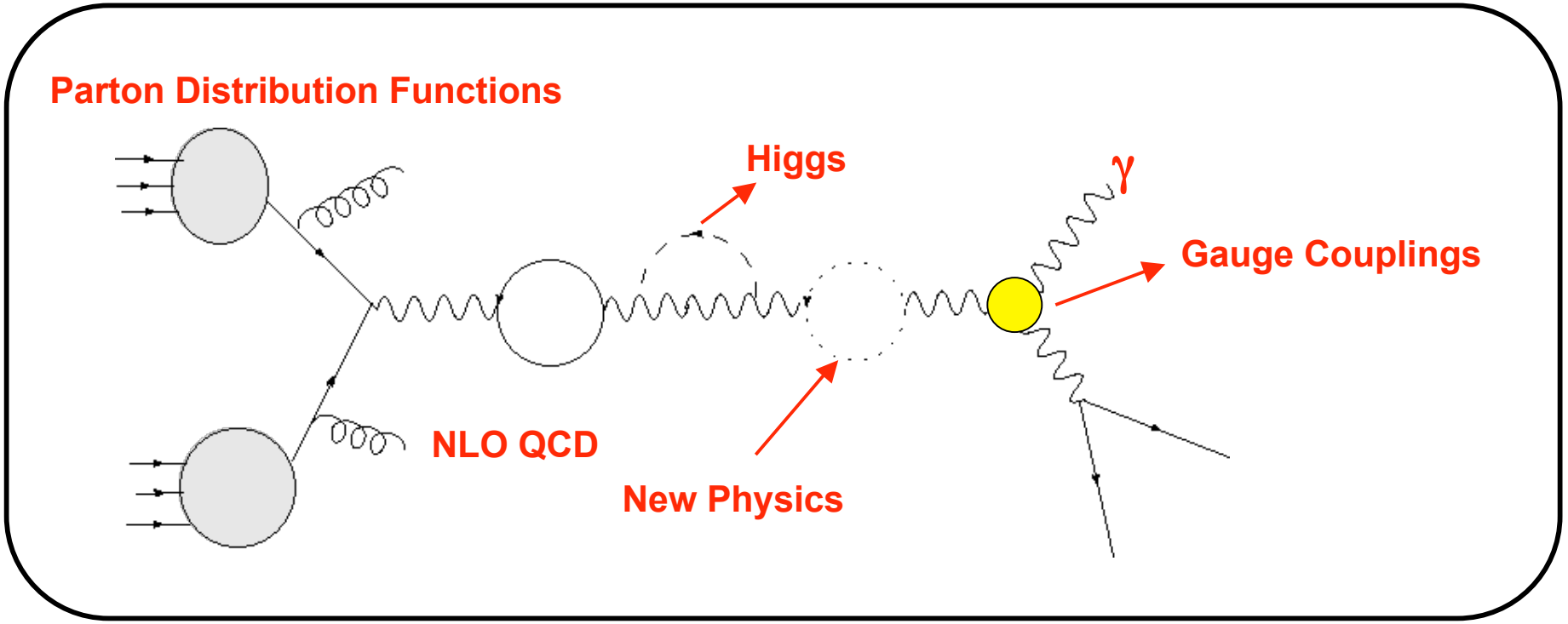
Motivation

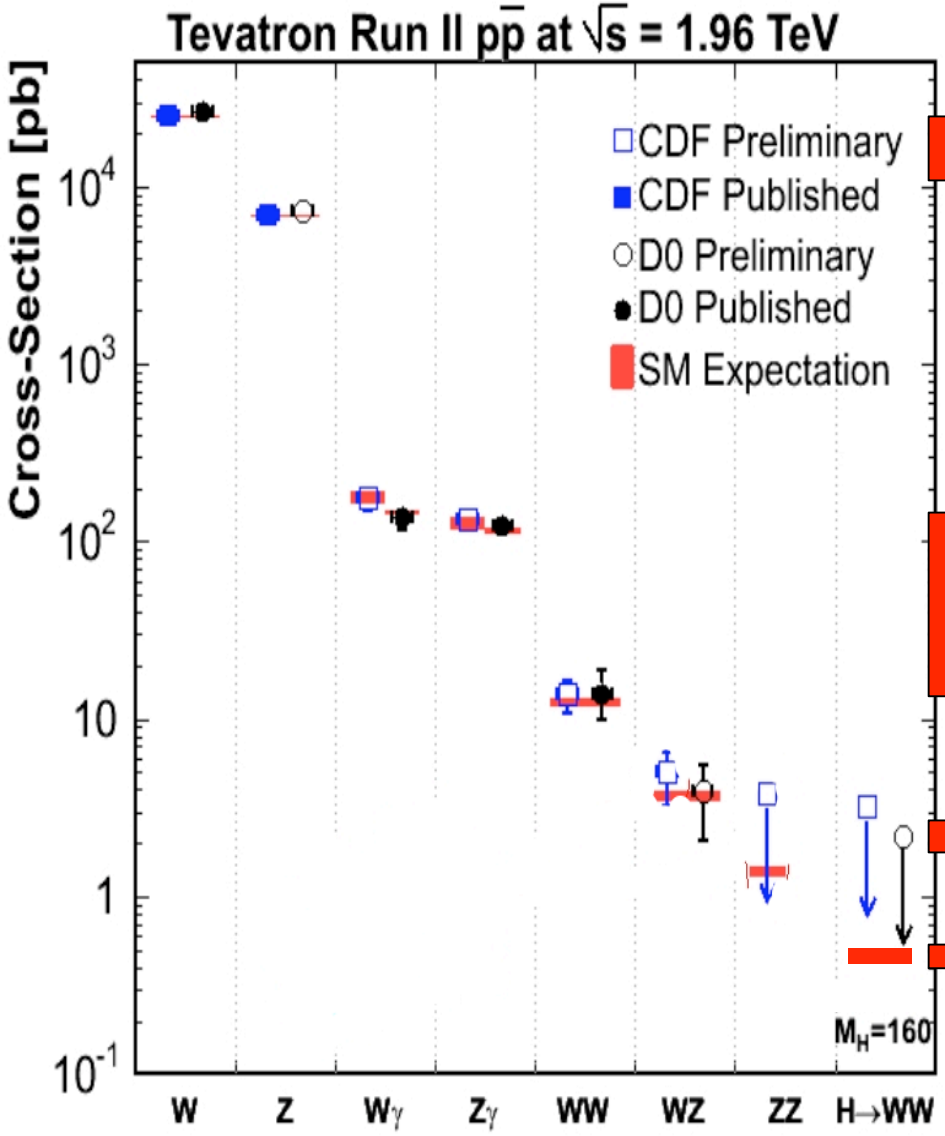
- Precisely calculated at (N)NLO

- Standard candles for calibration

- Backgrounds to new physics



Cross Sections / Overview



Single W,Z

Precision (loop) physics (0.2 fb^{-1})

Di-Bosons

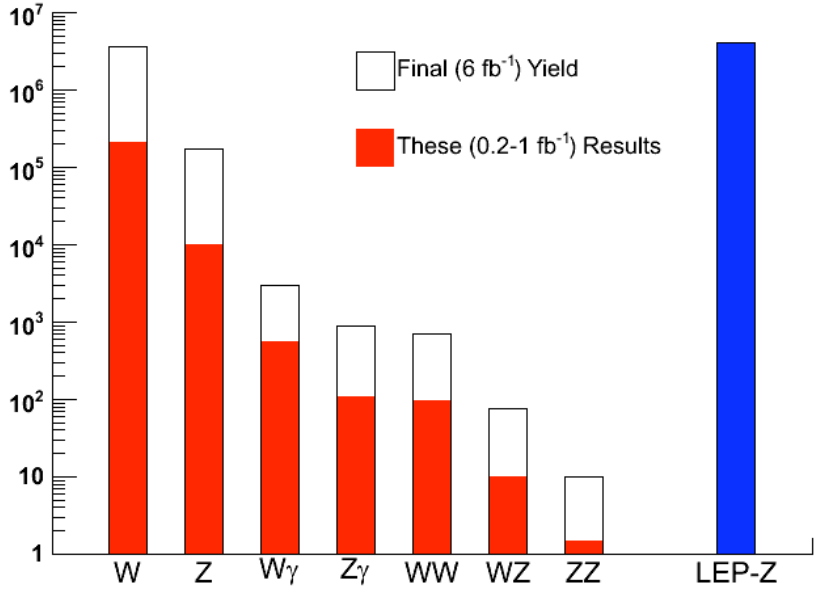
SM tests : gauge couplings (1 fb^{-1})

Single Top

Discovery / Observation (1-2 fb^{-1})

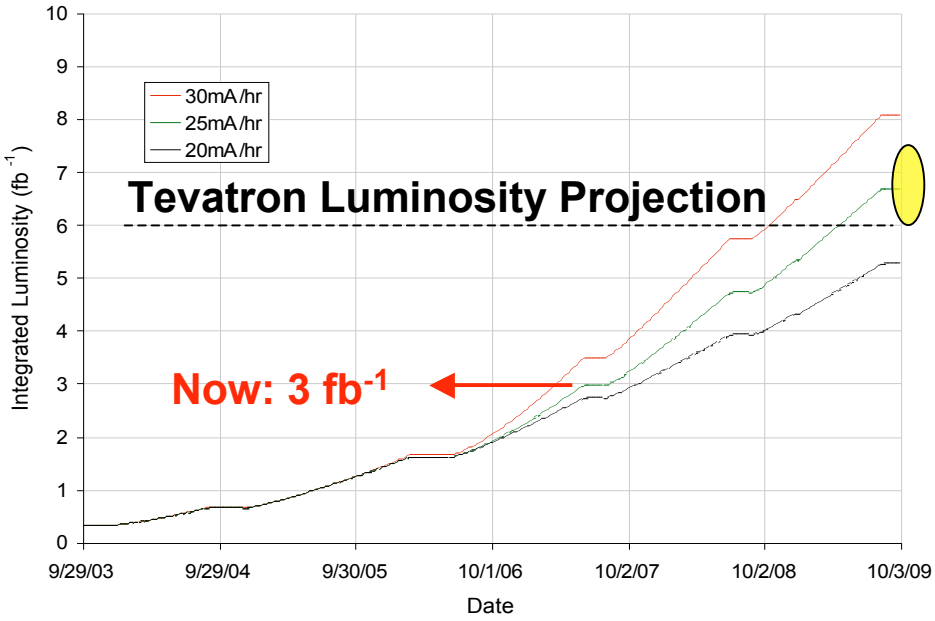
Higgs

Event Yields



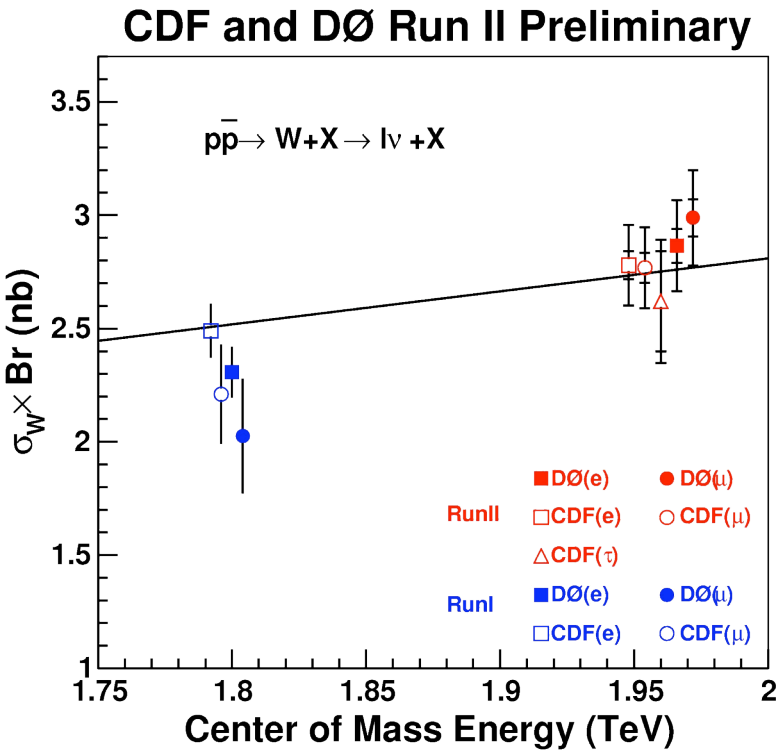
W yield is now approaching the Z yield at LEP.

Many results are now surpassing the precision achieved at LEP(2).



W & Z Cross Sections

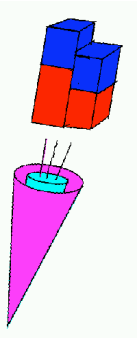
Precisely predicted to 2-3% at NNLO ~ exp. systematic (-lumi)
Measurements are now dominated by uncertainty in luminosity ~ 6%.



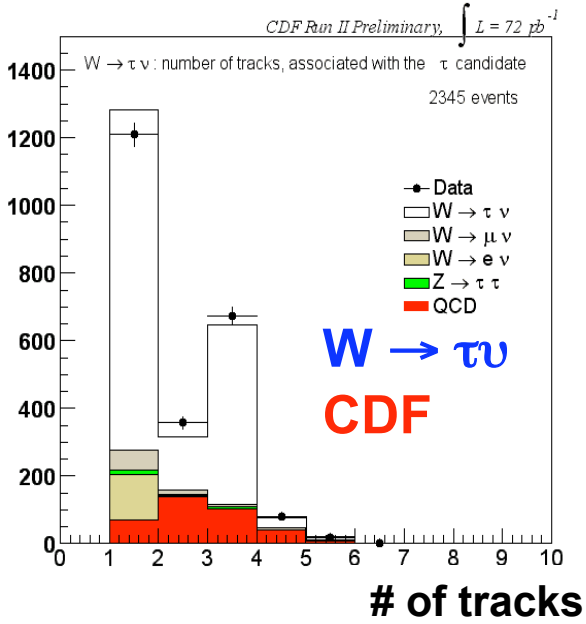
W cross section provides viable (integrated) luminosity measurement

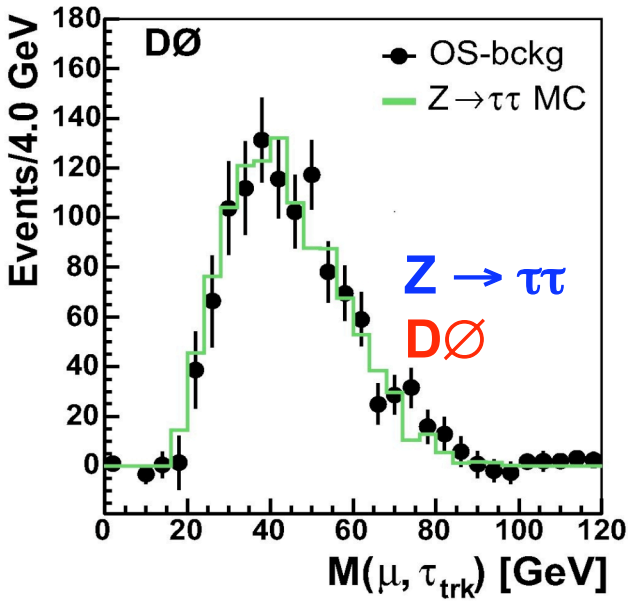
3rd Generation : Tau Channel

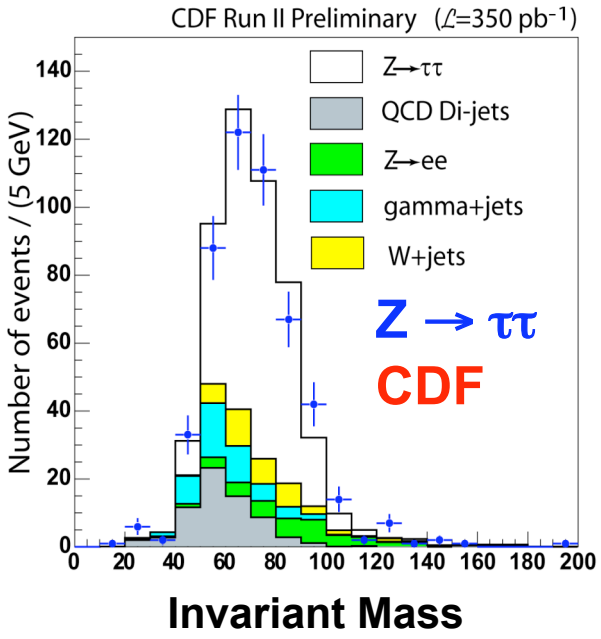
- test 3rd generation lepton universality
- benchmark for searches (especially MSSM Higgs).



Experimentally challenging
but good SM agreement at ~ 10% level





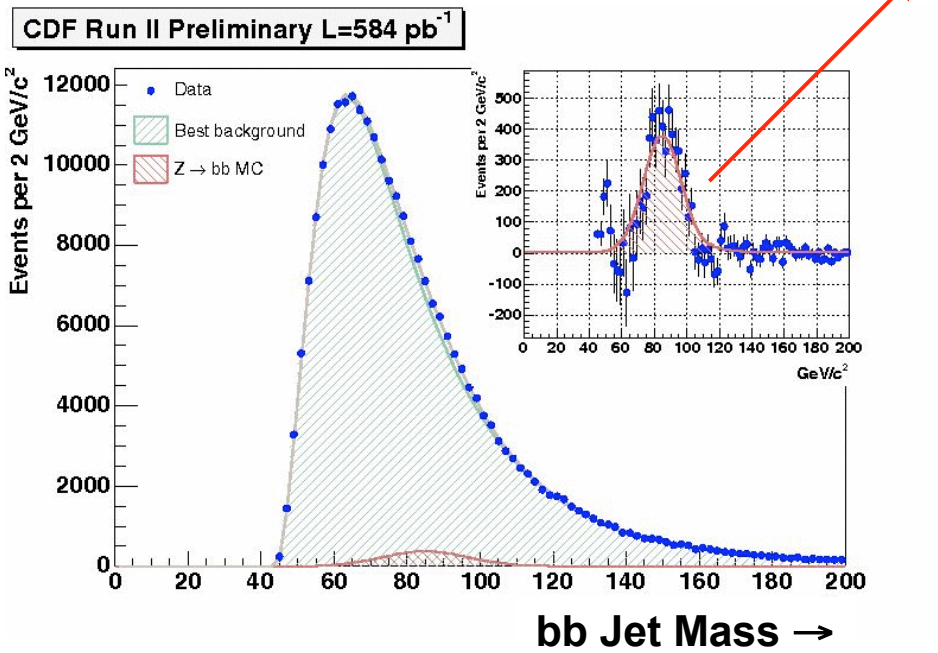


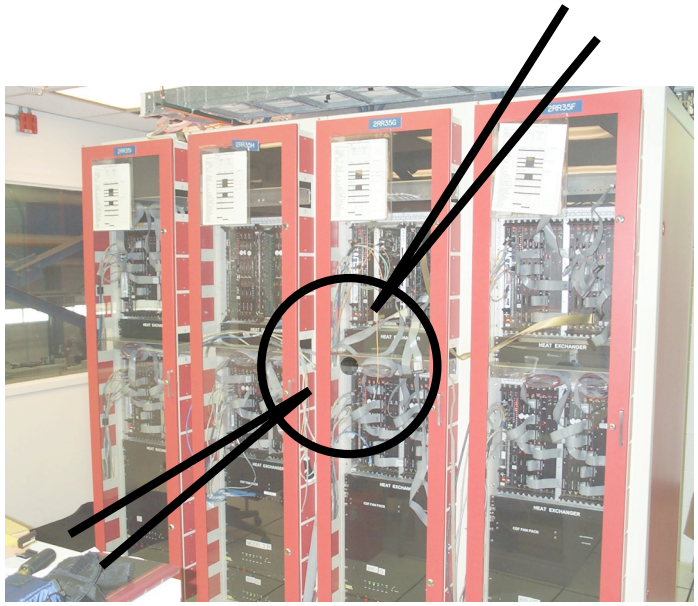
Lepton universality verified to 8%

3rd Generation : Z → bb

- first observation at a hadron collider

Signal : 5674 ± 448



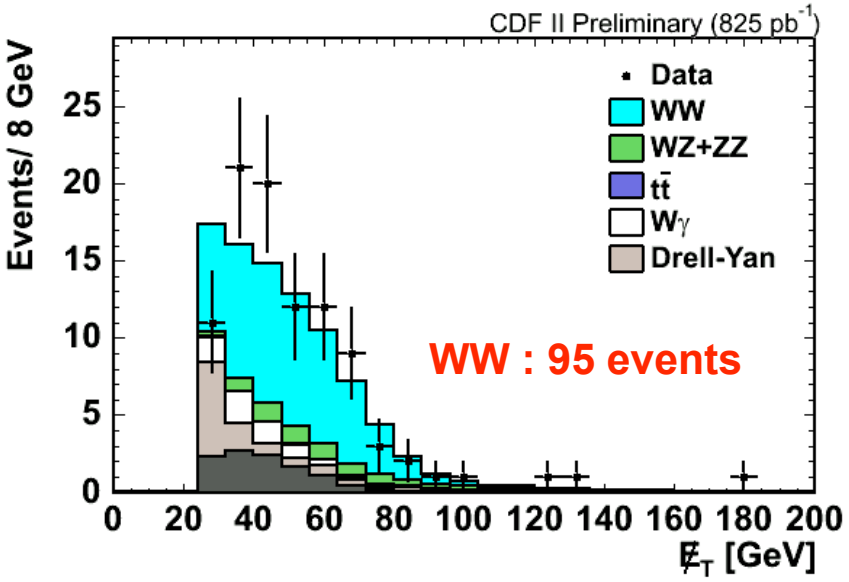


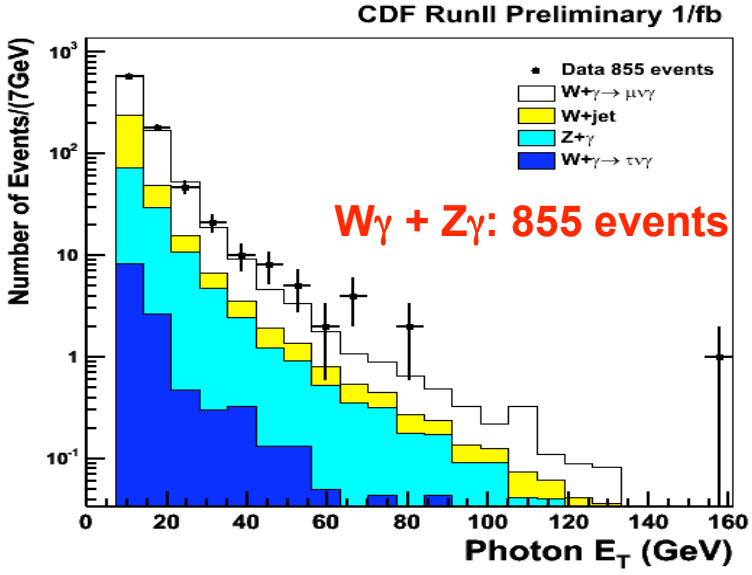
- important measurement to calibrate b-jet energy scale & resolution (h, top).

W+V, Z+V Cross Sections

The new SM benchmarks (& backgrounds) for our search programme.
Now all measured with 1fb^{-1}
Highlights :

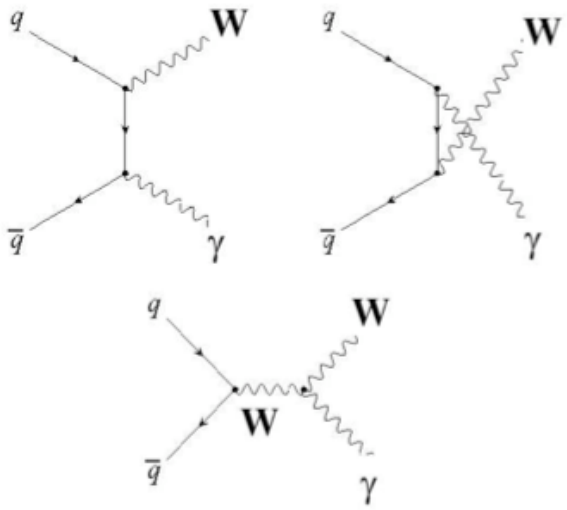
- Observation of radiation zero in Wγ
- Surpassing of LEP limits for Zγγ, ZZγ couplings from Zγ study
- First observation of WZ
- Hints of ZZ

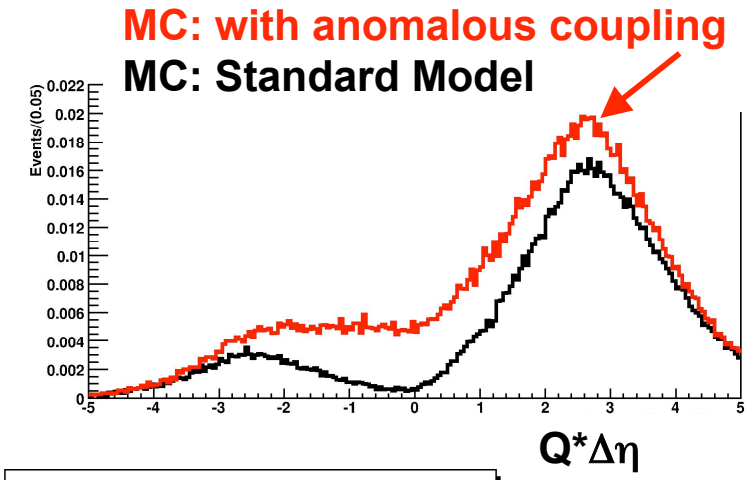


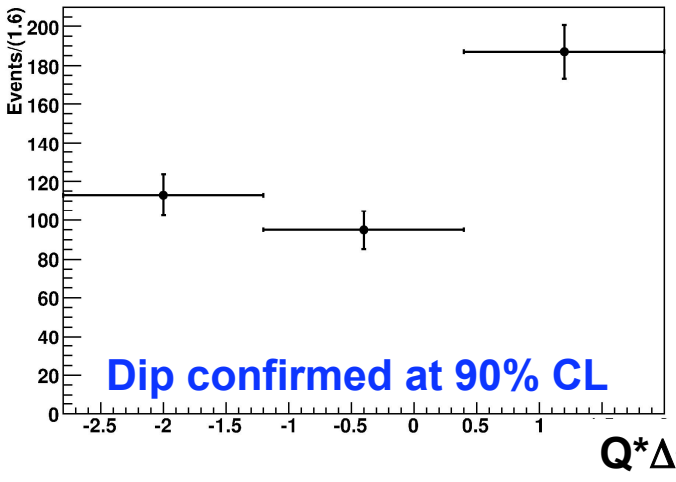


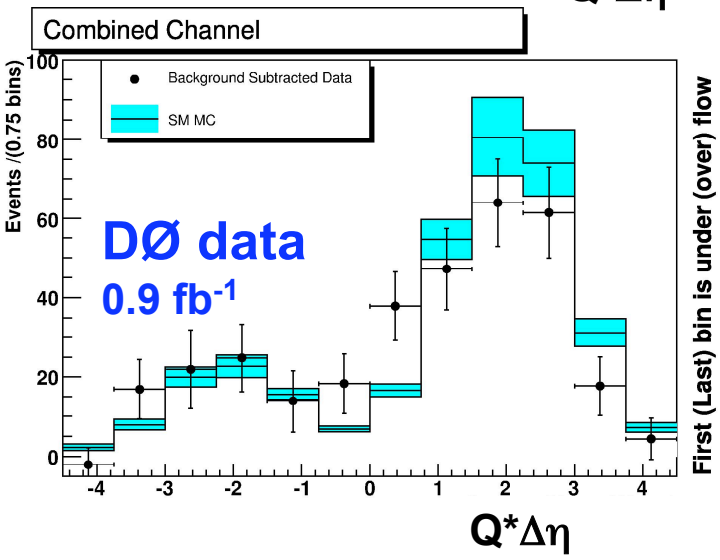
Wγ : Radiation Zero

Amplitude is zero for $\cos(\theta_{CM}) = -(1 + 2Q_d)$ but use $\eta_\gamma - \eta_{lepton}$ not θ_{CM}

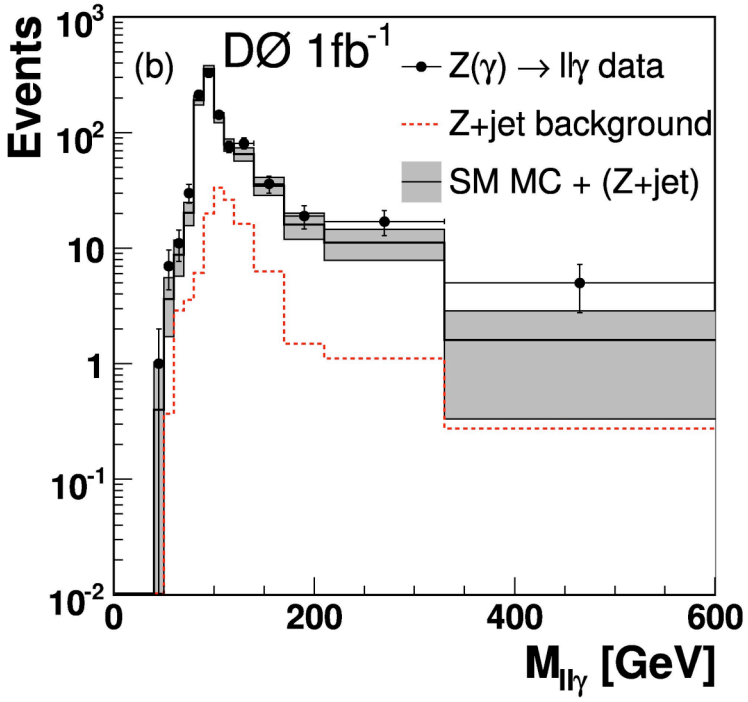


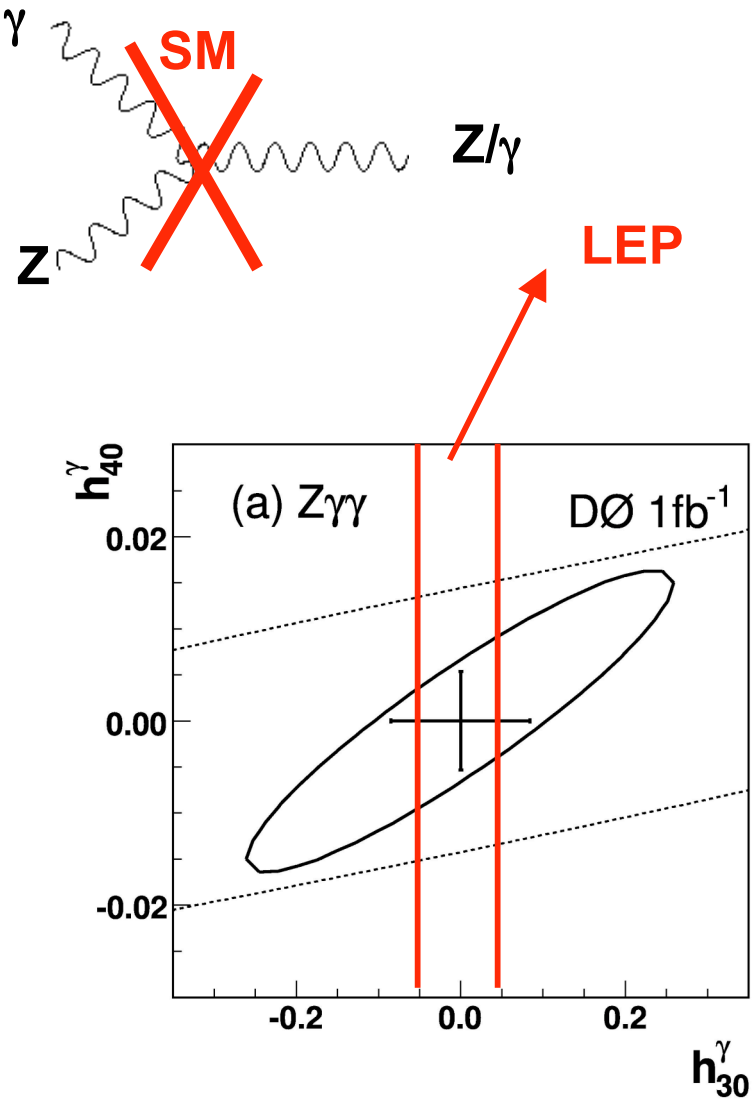






Zγ : Improved TGC Limits

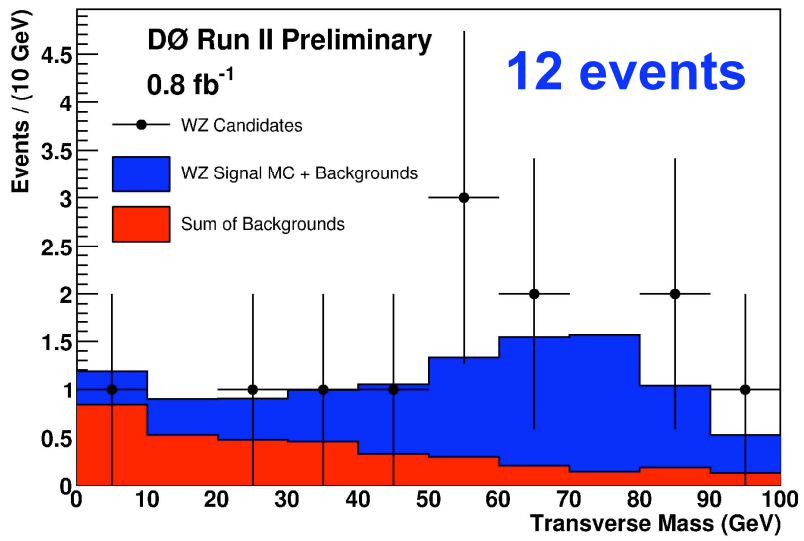


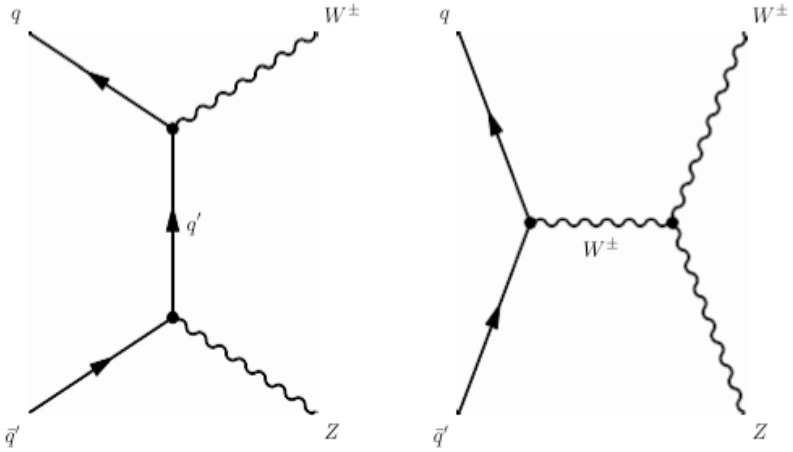


h_{40} limits now surpass LEP

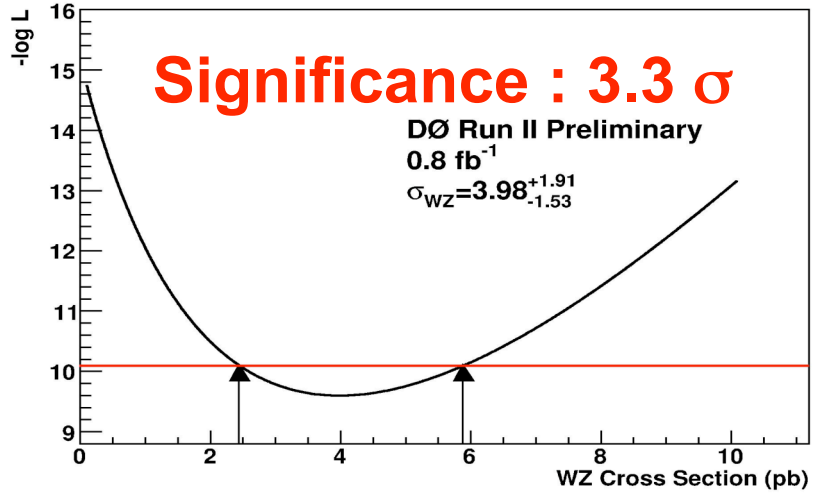
First Observation of WZ

WZ Candidate Transverse Mass

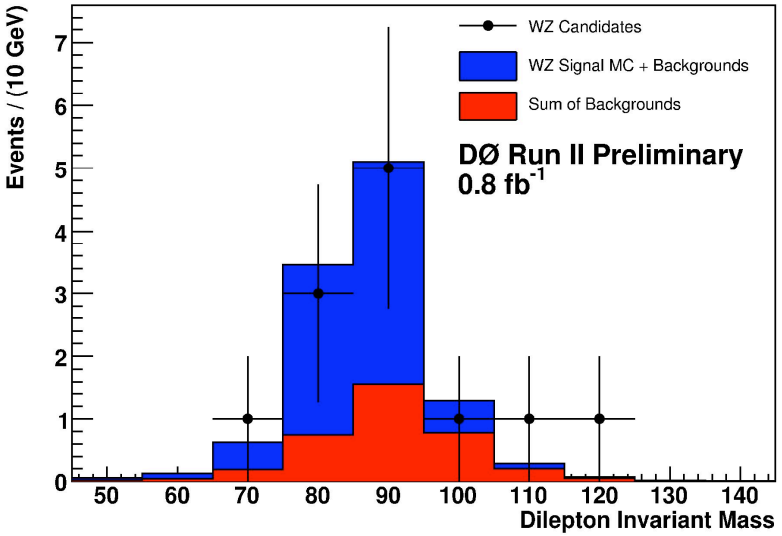




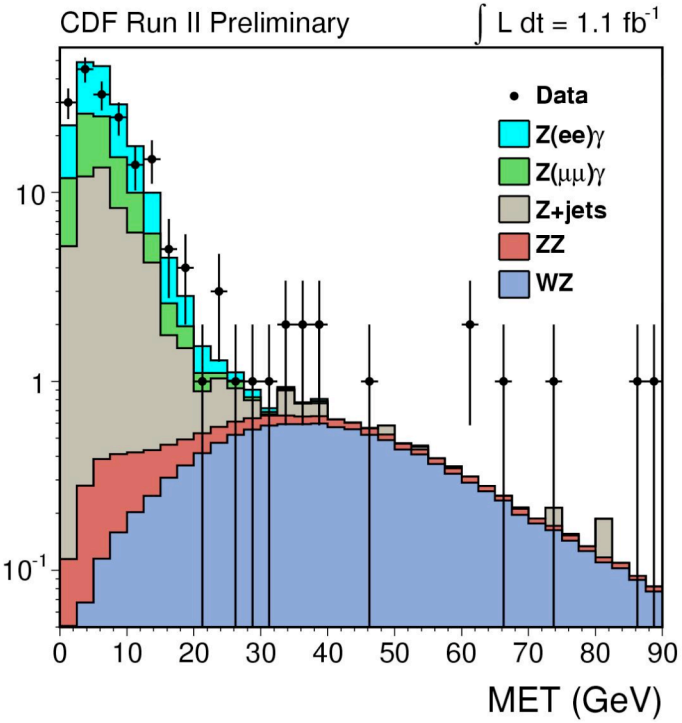
Histogram



WZ Candidate Dilepton Invariant Mass

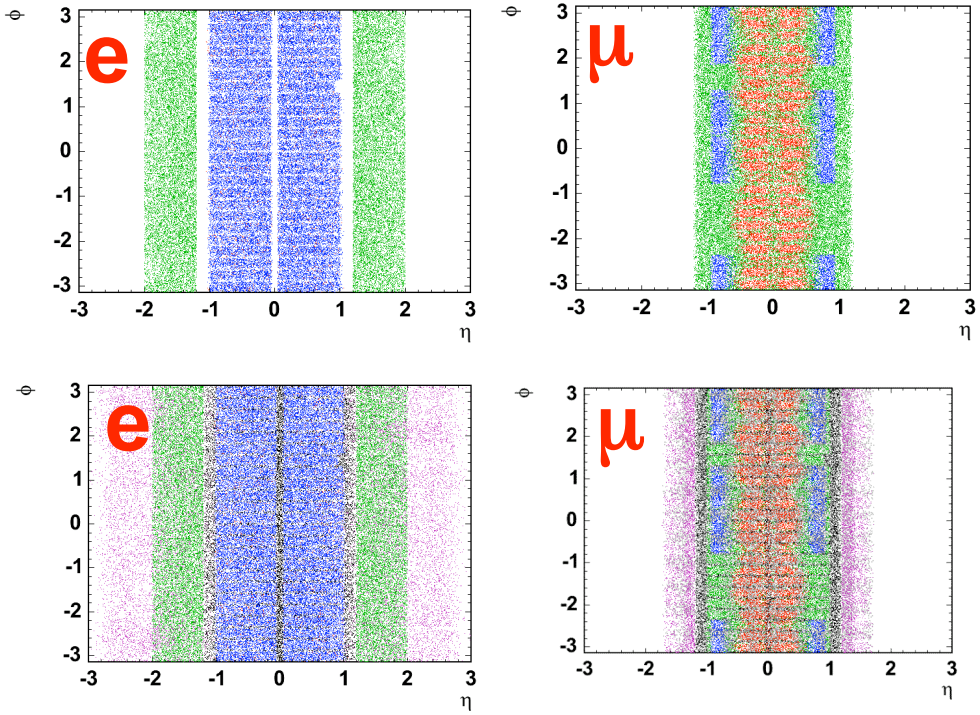


WZ Cross Section Measurement



Significance ~ 6σ

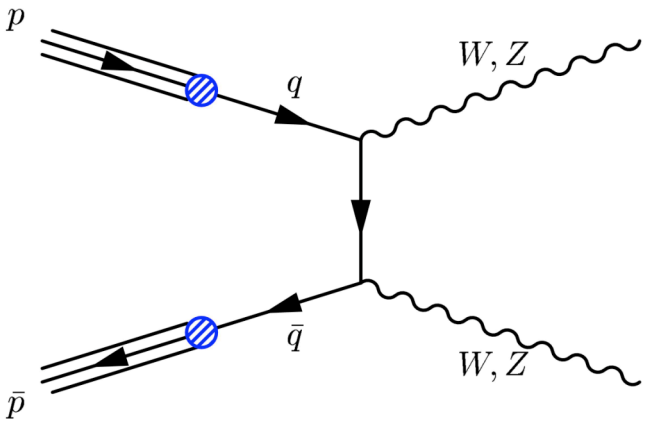
Made possible due to significant improvements in lepton acceptance

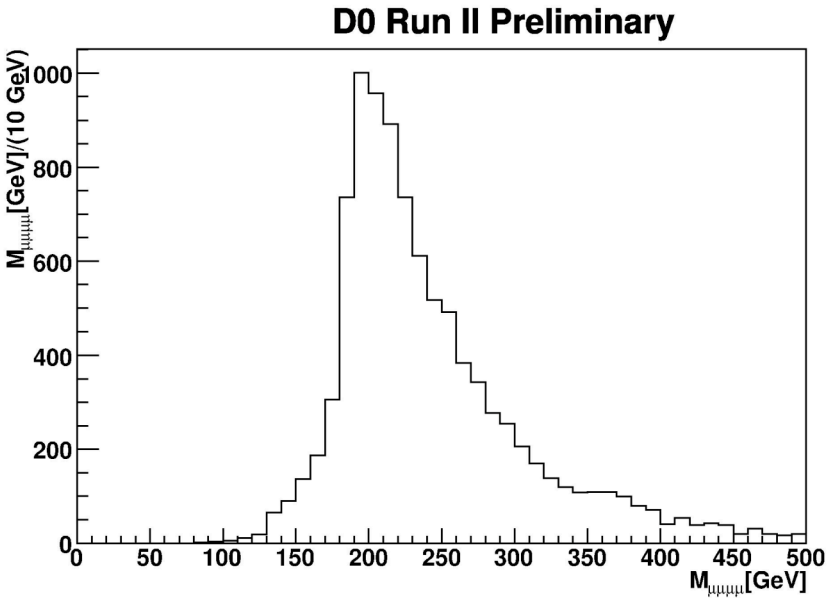


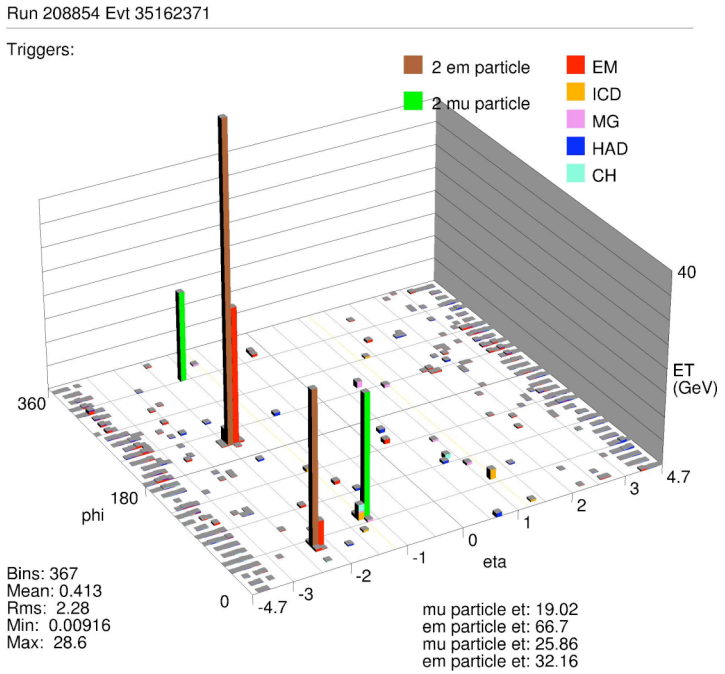
$$\sigma(p\bar{p} \rightarrow WZ) = 5.0^{+1.8}_{-1.6}\,\text{pb}\ (\text{Theory} = 3.7 \pm 0.3\ \text{pb})$$

WZ TGCs though not yet competitive with LEP2

First Hints Of ZZ Signal





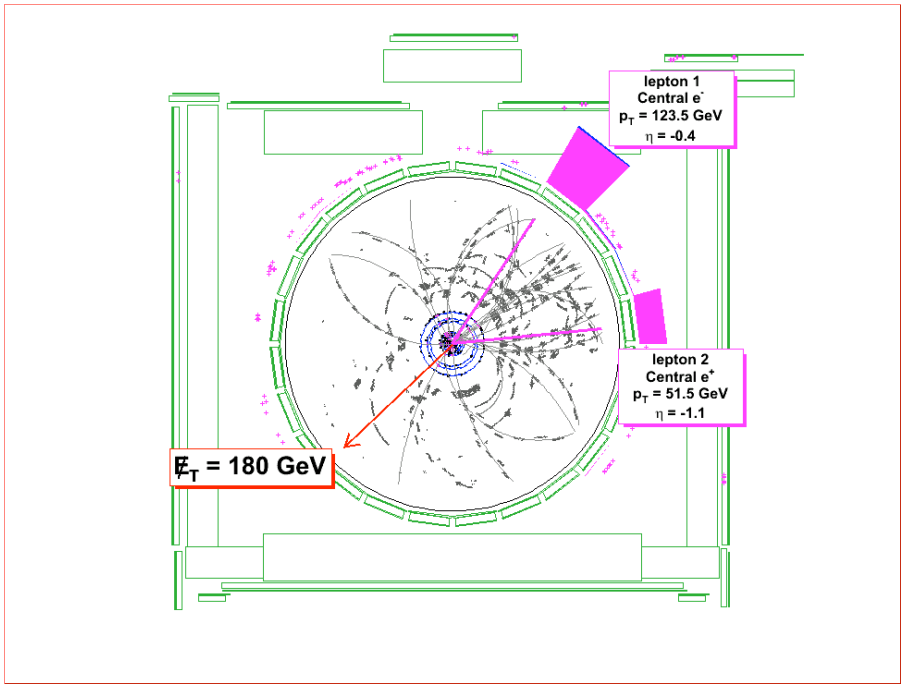


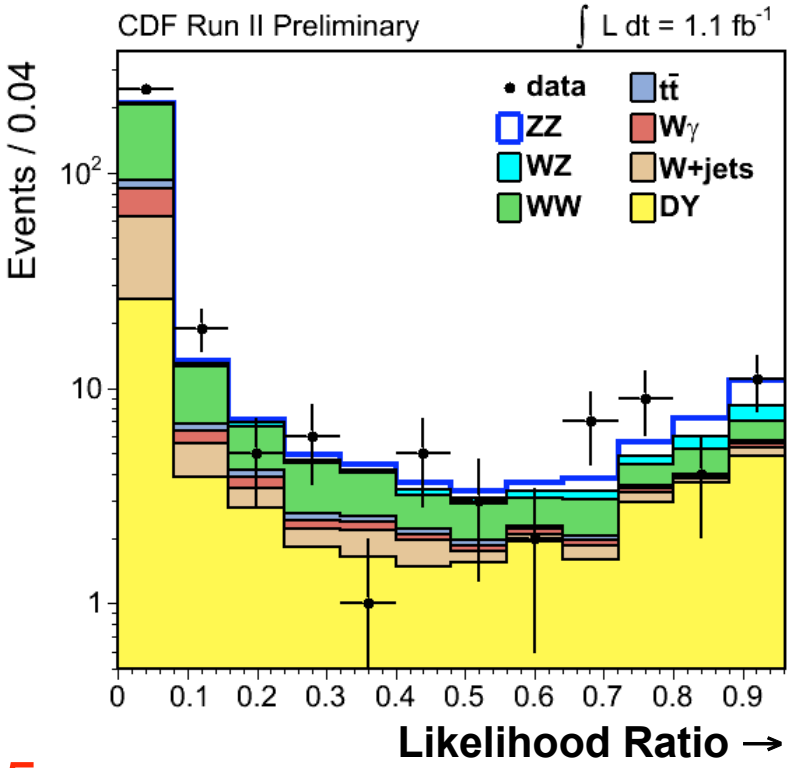
1 eeμμ candidate
Expected ~ 1.5

$\sigma < 4.3$ pb (95% CL)

First Hints Of ZZ Signal

CDF has combined 4l & llνν channel for greater significance





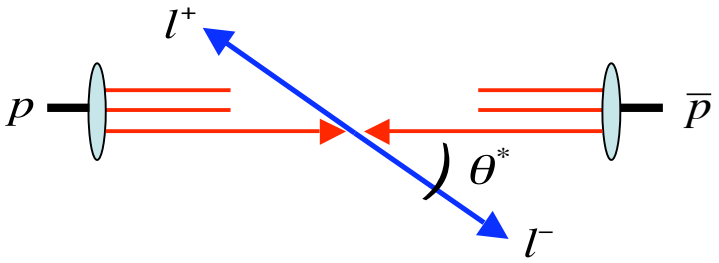
1 eeμμ candidate; expected ~ 2.5

$$\sigma(ZZ) = 0.75^{+0.71}_{-0.54}\ \text{pb}$$

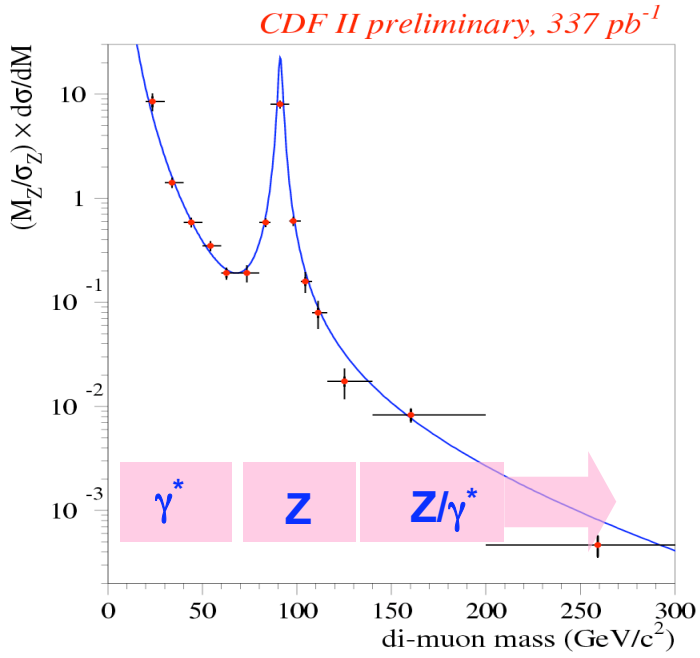
σ < 2.1 pb (95% CL)

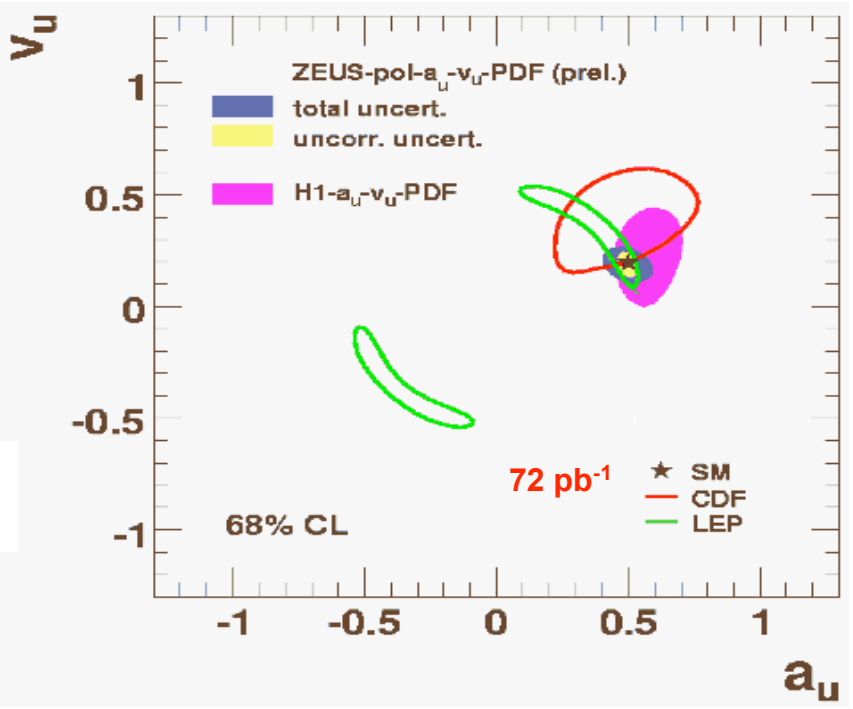
Angular Distributions: A_{FB}

- angular distributions allow constraints on Parton Distribution Functions and anomalous quark couplings to be made



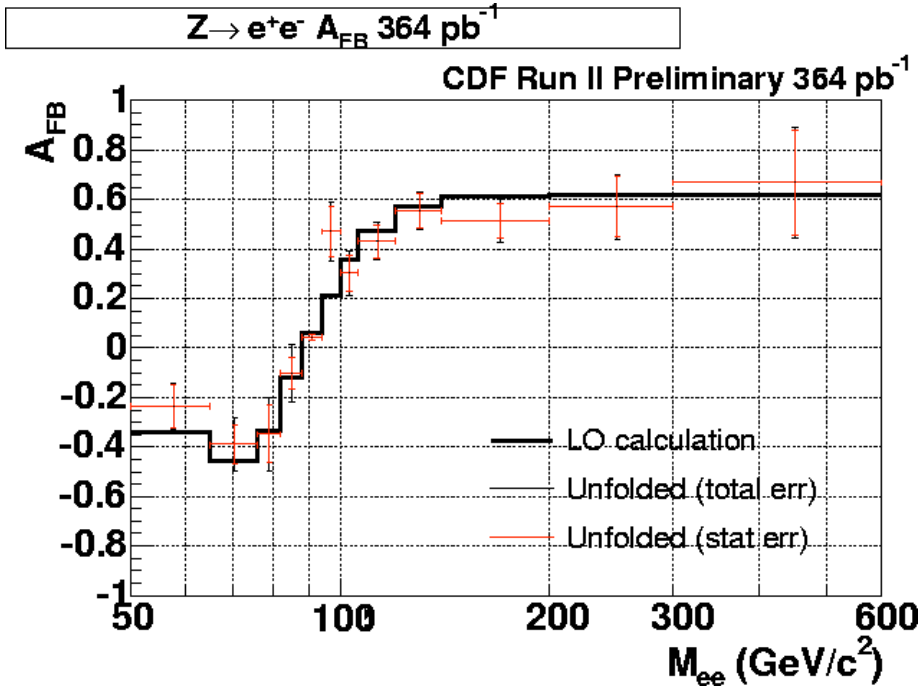
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

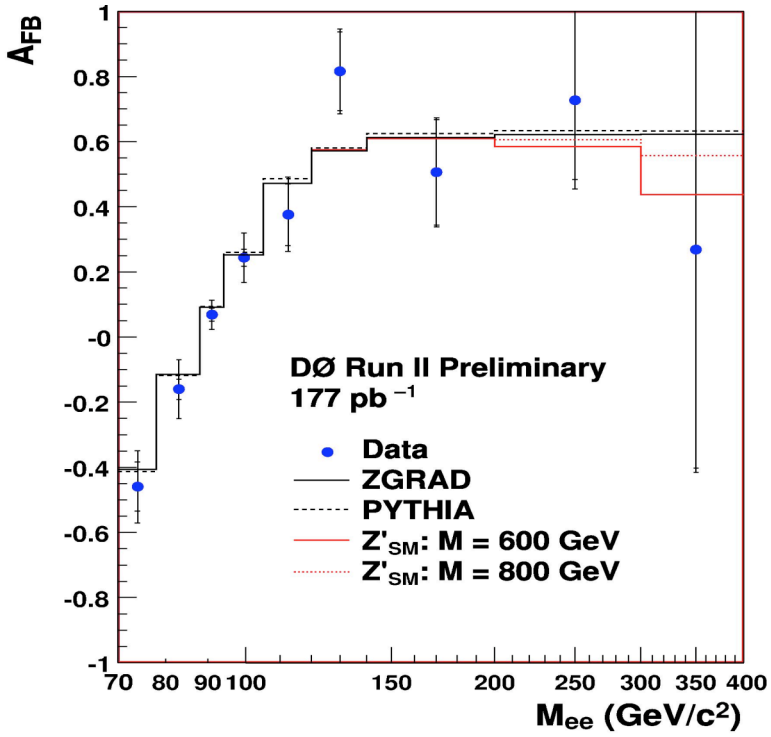




A_{FB} Above Z Pole

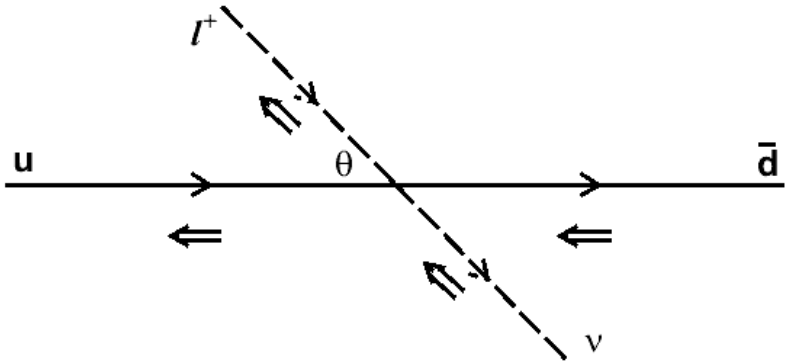
- statistics limited but ultimately sensitivity to Z' beyond SM.



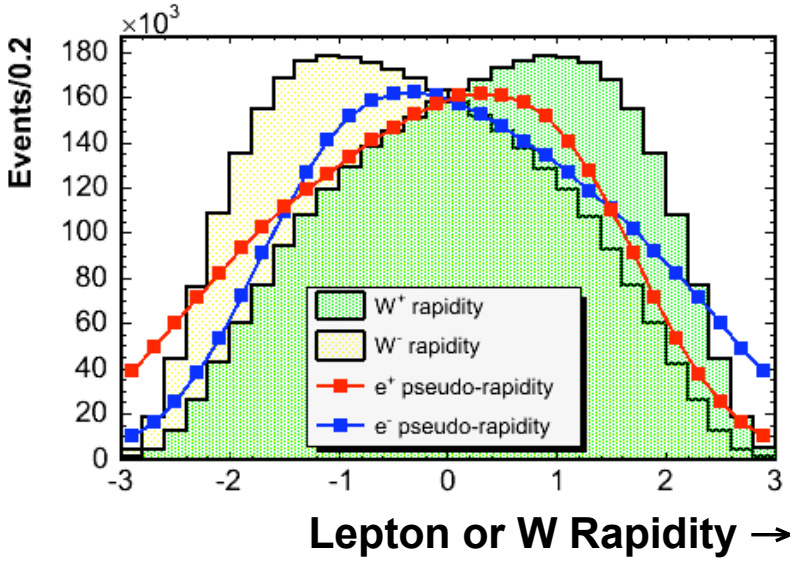


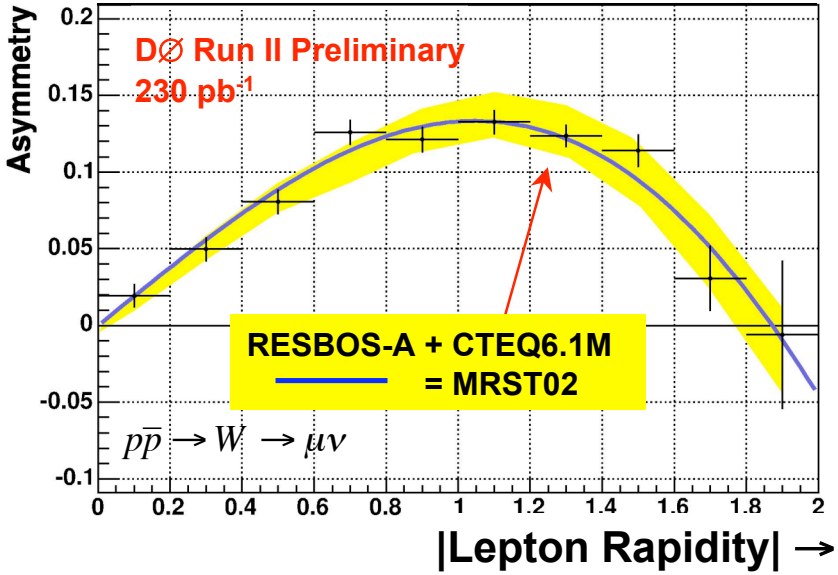
W Charge Asymmetry

- W^+ boosted in proton direction since u quark momentum > d quark

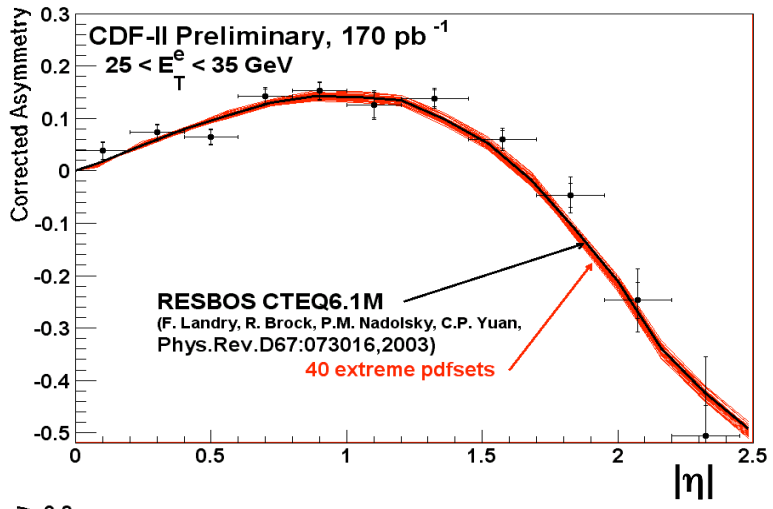


- we measure a lepton charge asymmetry



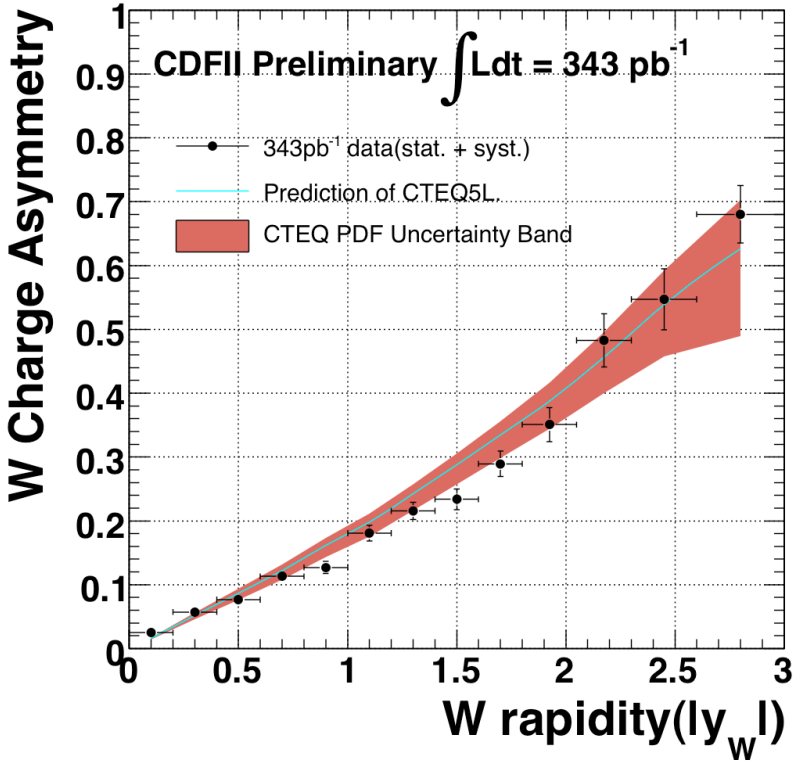


W Charge Asymmetry



Improved constraints if split data by E_T

Ultimately best constraints by measuring W charge asymmetry using weighted iterative estimate of W rapidity.

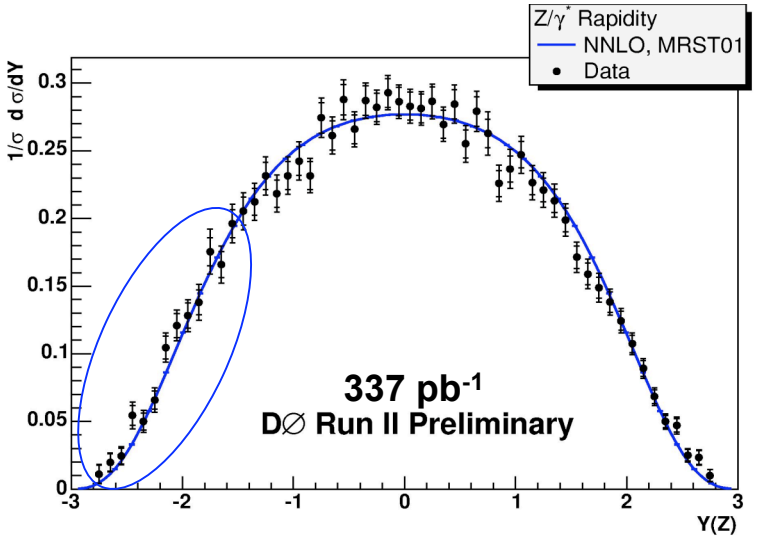


Drell Yan Rapidity

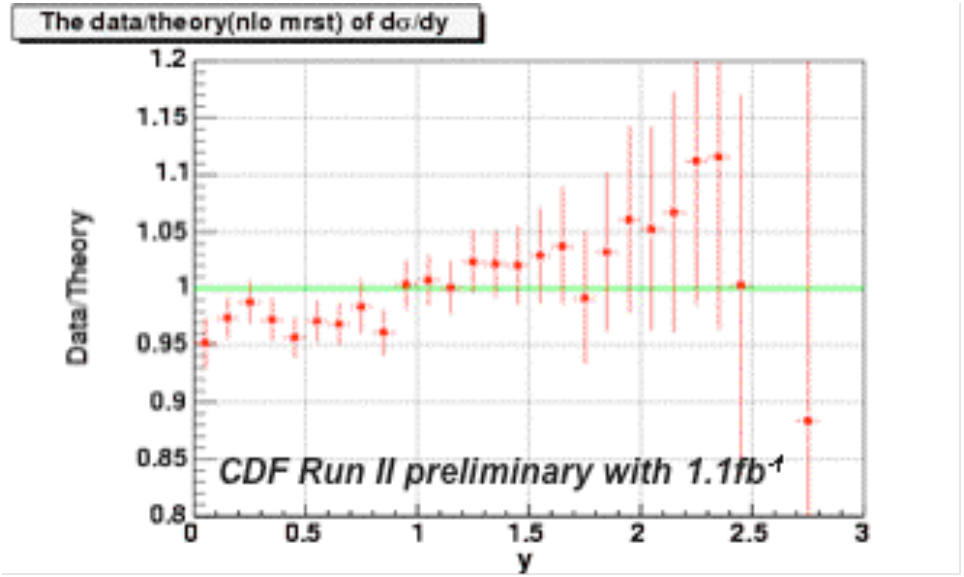
- Z boson rapidity well measured from decay leptons

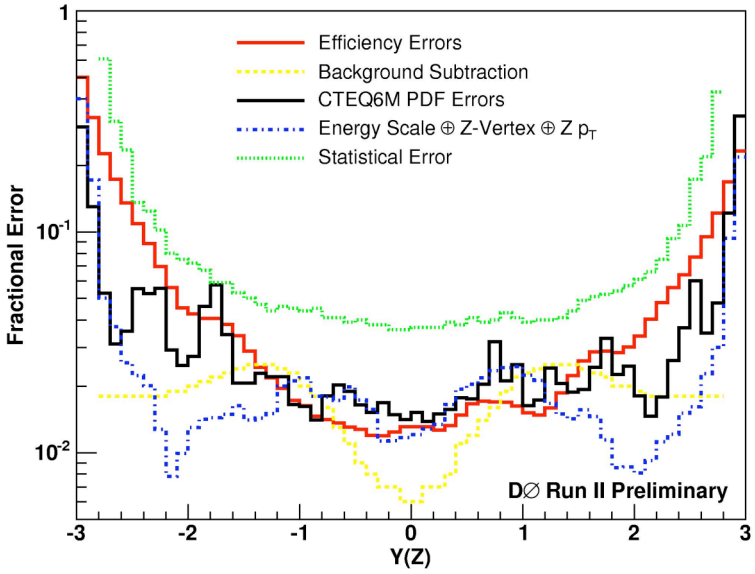
$$Y_Z = 0.5 \ln\left(\frac{x_p}{x_{\overline{p}}}\right)$$

High Y_Z
Probes one high *x*
& one low *x* parton



Statistics limited but with data in hand expect reduced PDF uncertainties at high-x

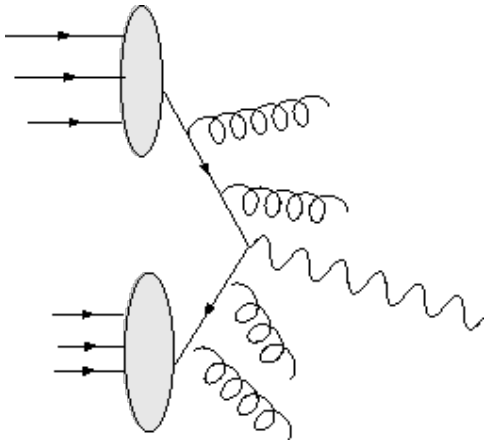


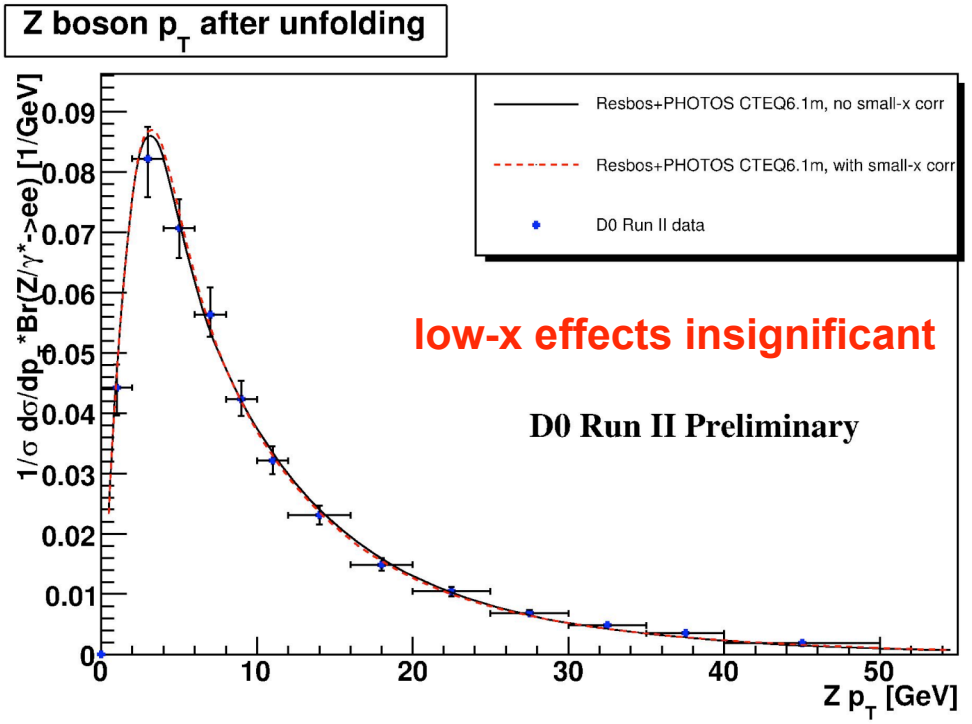


Drell Yan P_T

PDFs determine boson rapidity

W,Z pT determined by QCD radiation

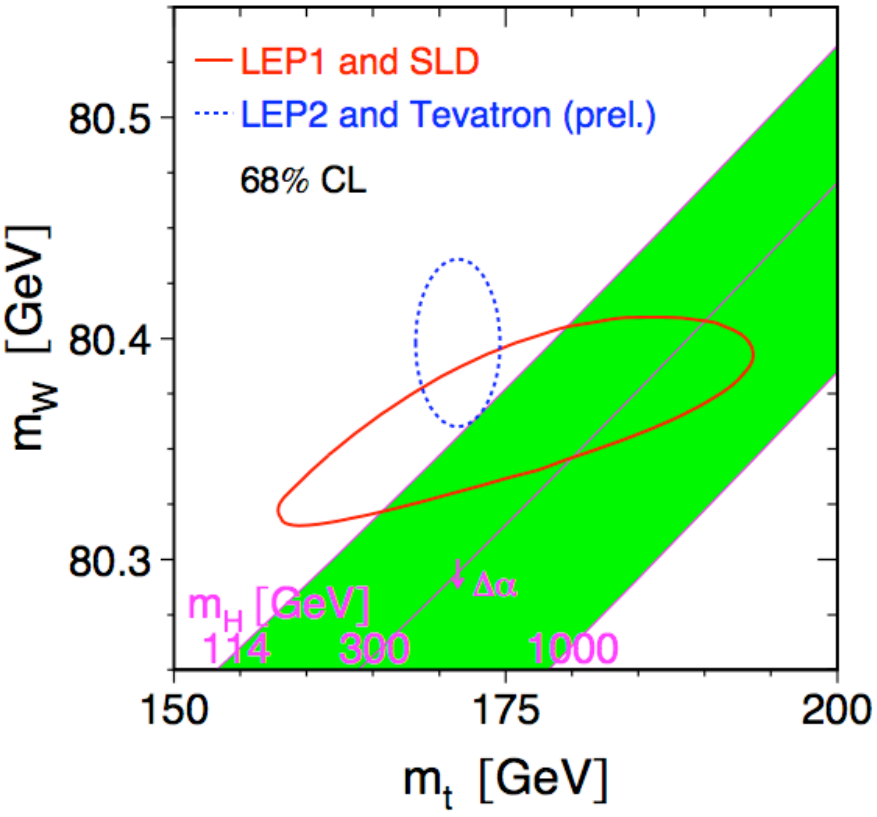




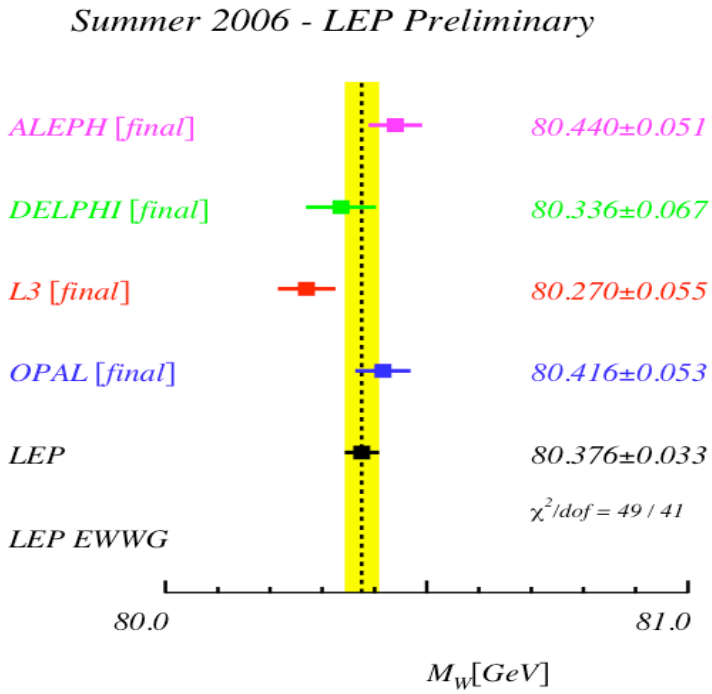
QCD radiation at low p_T is non-perturbative and requires data to constrain an ad-hoc intrinsic p_T parameterisation.

Important ingredient in W mass analysis

W Mass Motivation



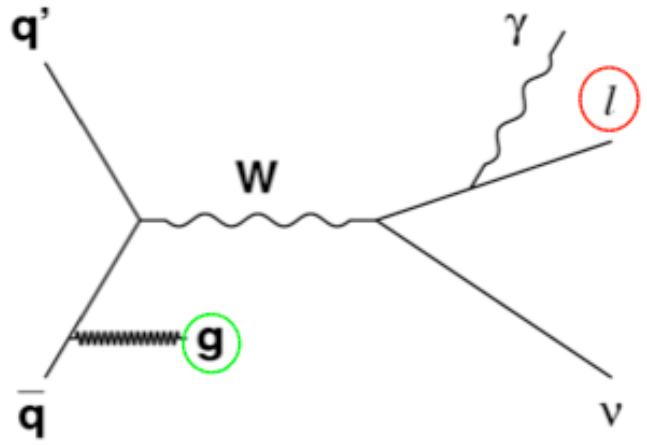
$\Delta m_T \sim 1.8$ GeV (1.1%)

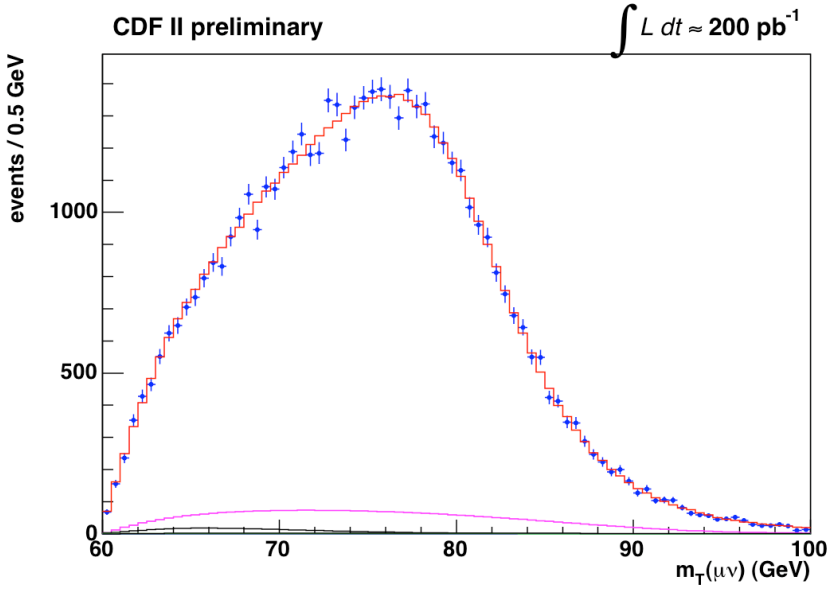


W mass uncertainty is the limiting uncertainty on constraining the Higgs mass.

Need $\Delta m_w \sim 11$ MeV (0.014%) for top & W to have equal weight in m_H constraint

W Mass Strategy





Lepton Momentum
- calibrate from J/ψ and upsilons
- cross check with Z → μμ

Lepton Energy
- calibrate using E/p
- cross check with Z → ee

Backgrounds
- reduce below 1% by cuts

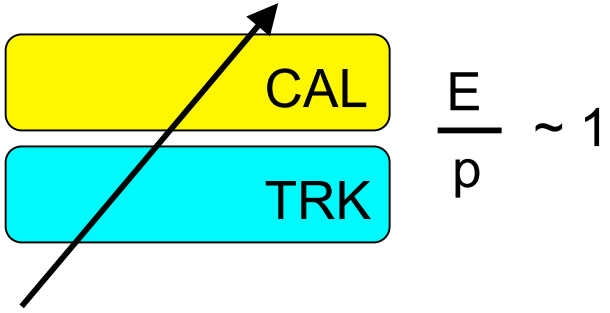
$$M_T = \sqrt{2p_T^l p_T^\nu (1 - \cos\phi_{l\nu})}$$

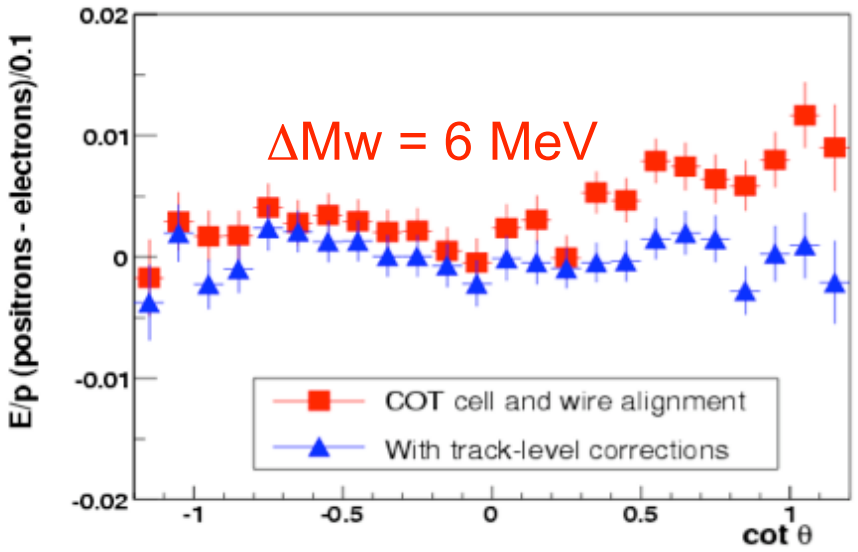
$$\vec{p}_T^{\,\nu} = -(\vec{U} + \vec{p}_T^{\,l})$$

Mw : Momentum Calibration

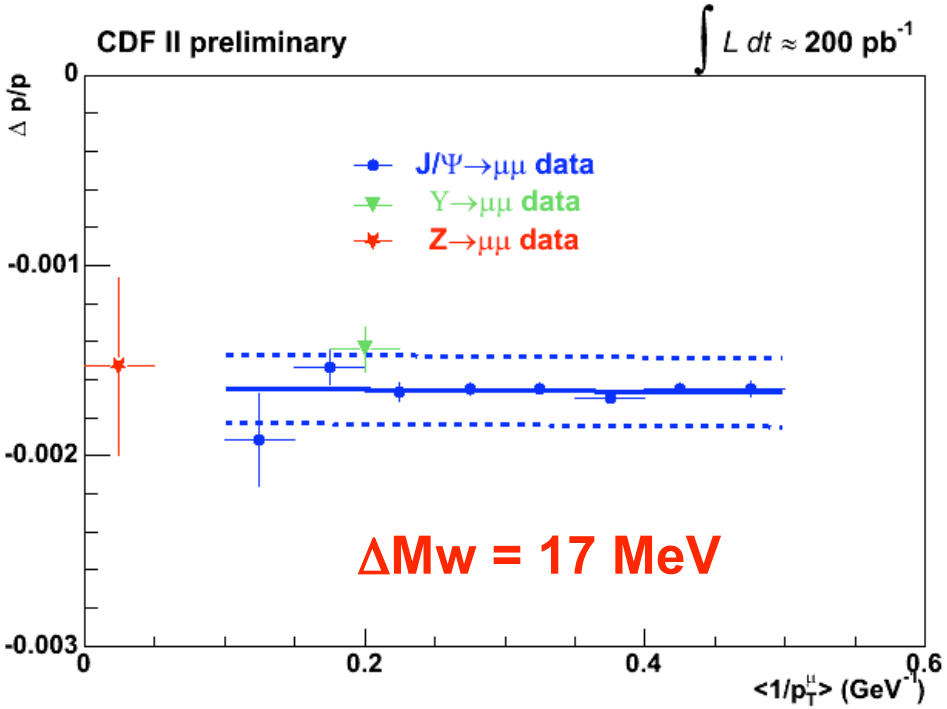
Key ingredients

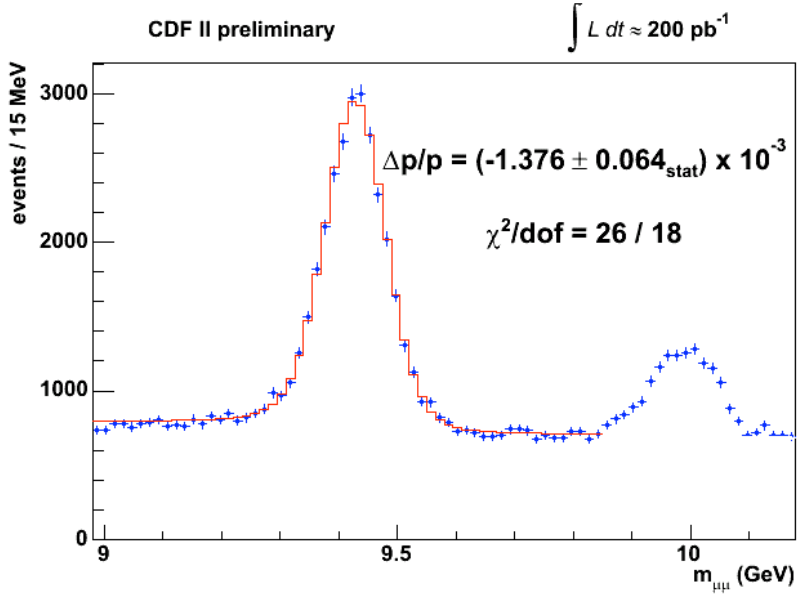
- material map : amount and type (CDF has ~ 20% X_0)
- tracker alignment
  - use cosmics & W events
  - use E/p from low energy inclusive electron events





Mw : Momentum Calibration





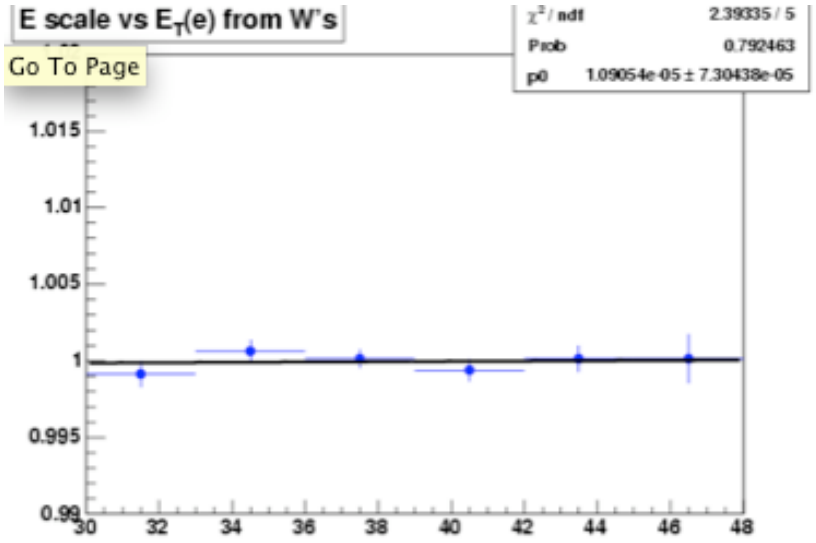
Scales consistent between Z, J/Ψ, Υ

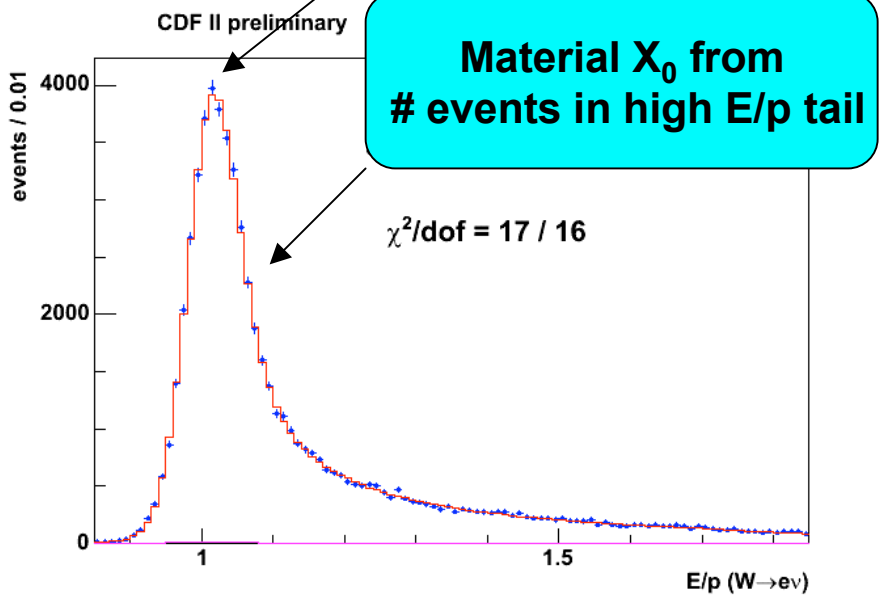
Mw : Energy Calibration

Three error sources:

- statistical + mom scale
- material before calorimeter
- response of calorimeter vs E

Mz (from E/p) - Mz (PDG) = 3 ± 67 (stat) MeV





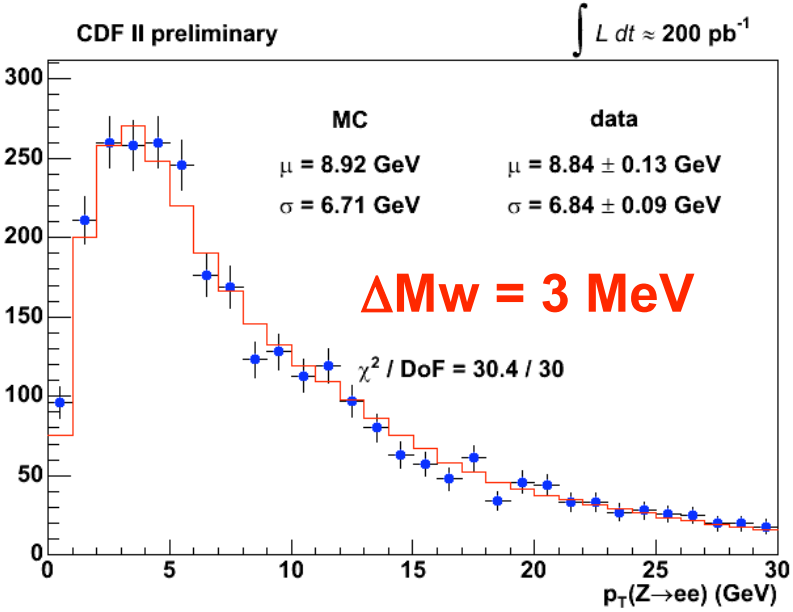
Fit scale in peak region

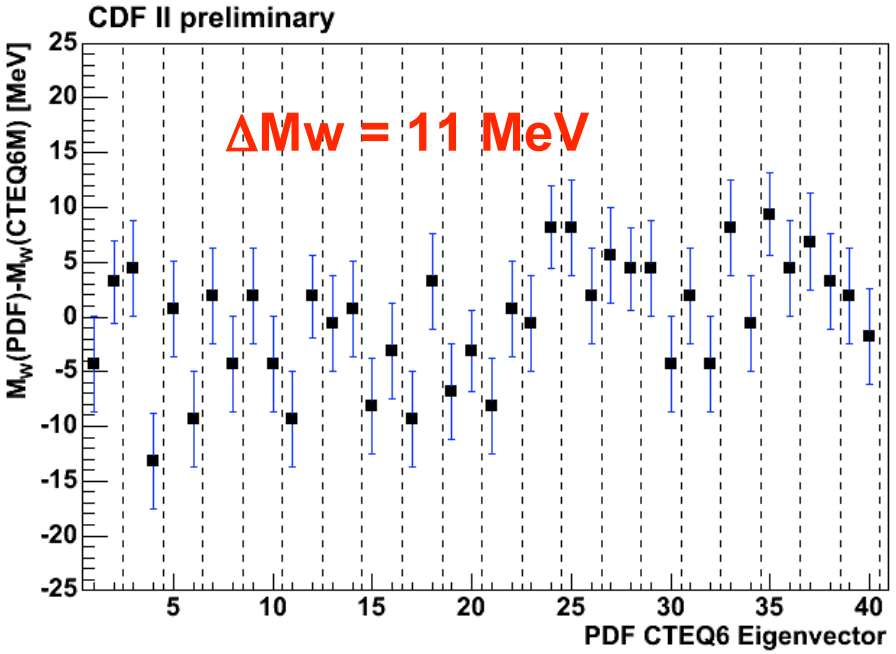
Material X_0 from # events in high E/p tail

ΔMw ~ 22 (stat) ⊕ 11 (material) ⊕ 17 (p-scale) = 30 MeV

Mw : QCD/QED Uncertainties

- QCD uncertainties from PDFs and W p_T





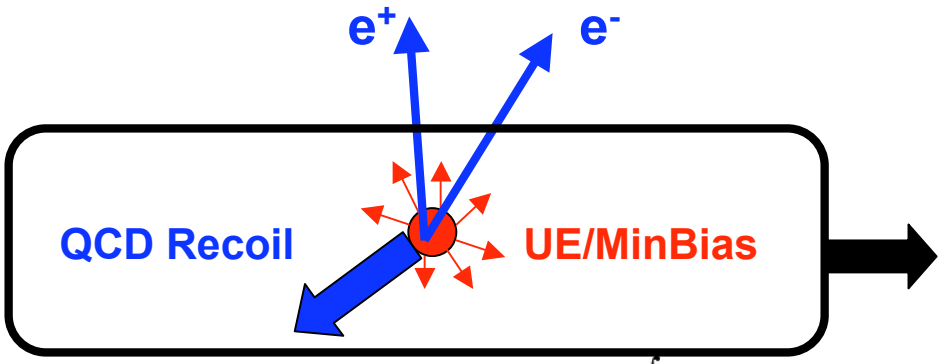
- QED uncertainties from approximations in O(α^2) treatment

ΔMw = 11 MeV

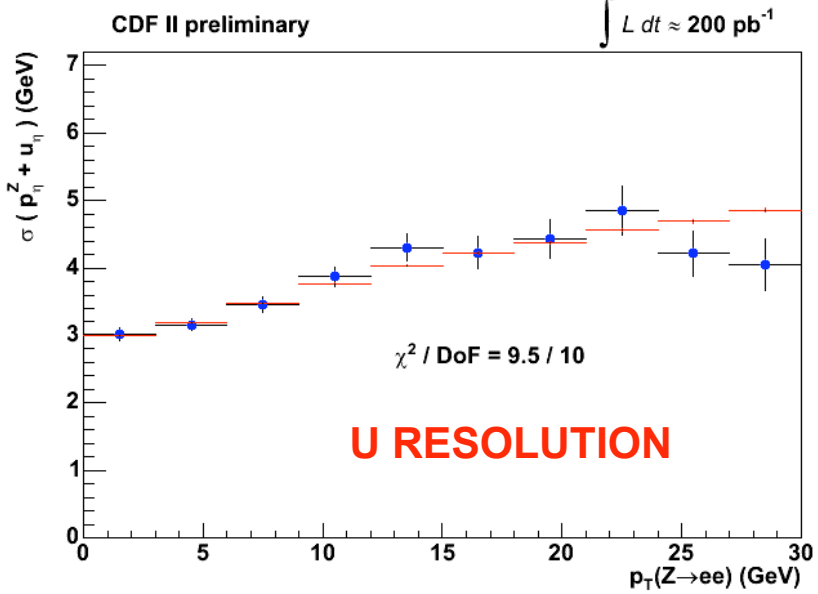
Mw : Recoil Model

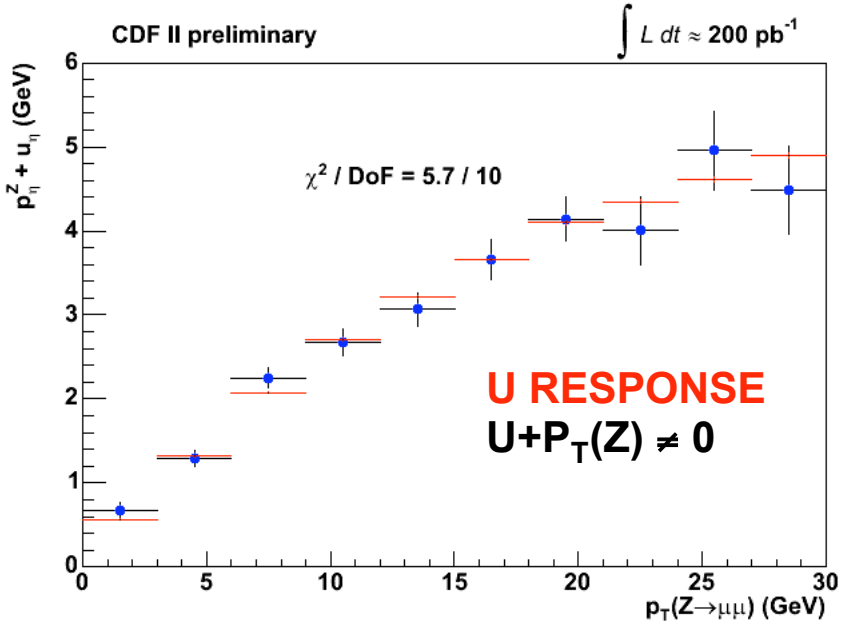
Neutrino p_T is inferred from lepton p_T and "rest" of the event

"rest" : QCD radiation "recoiling" against W; overlapping min bias; underlying event



U + P_T(Z) not quite zero



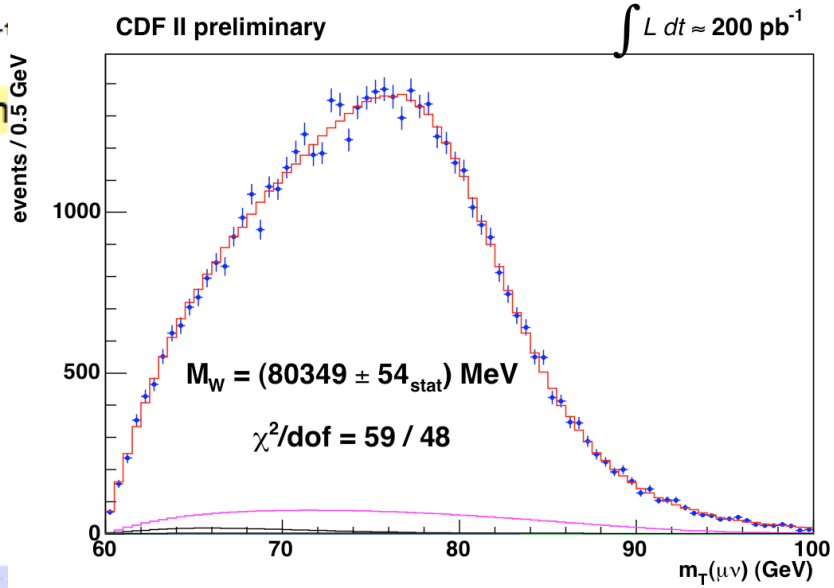


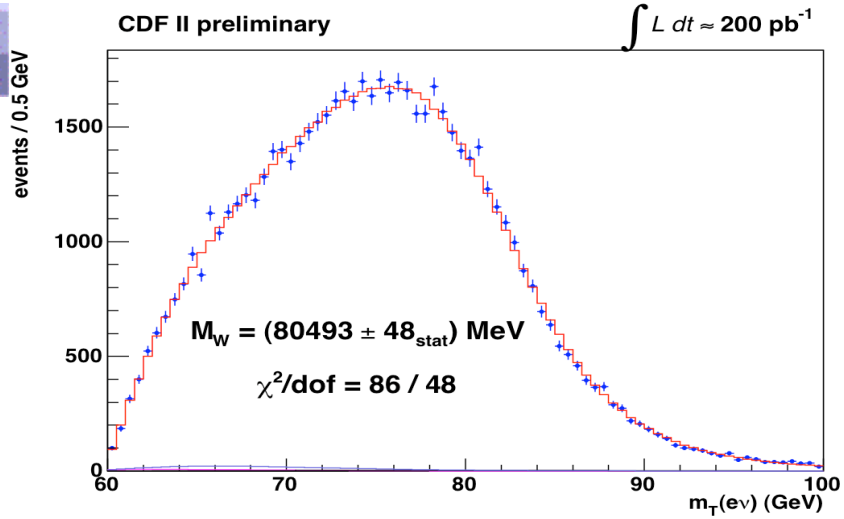
Mw : CDF Result

CDF II preliminary L = 200 pb^{-1}

m_T Uncertainty [MeV]	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
$u_{\parallel}$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

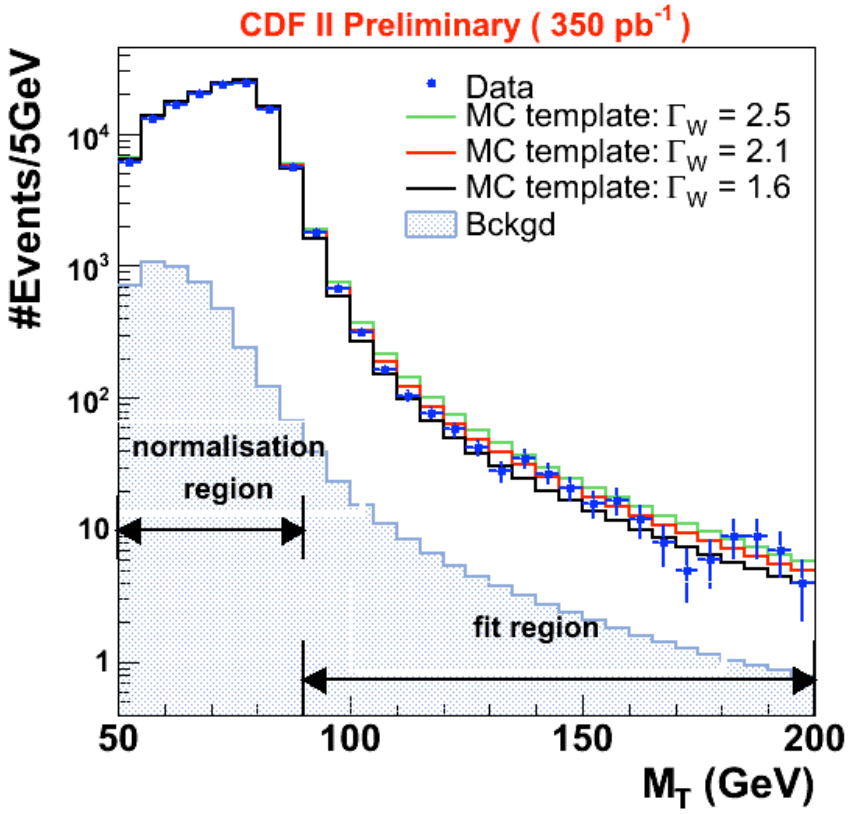
$M_W = 80413 \pm 48$ MeV





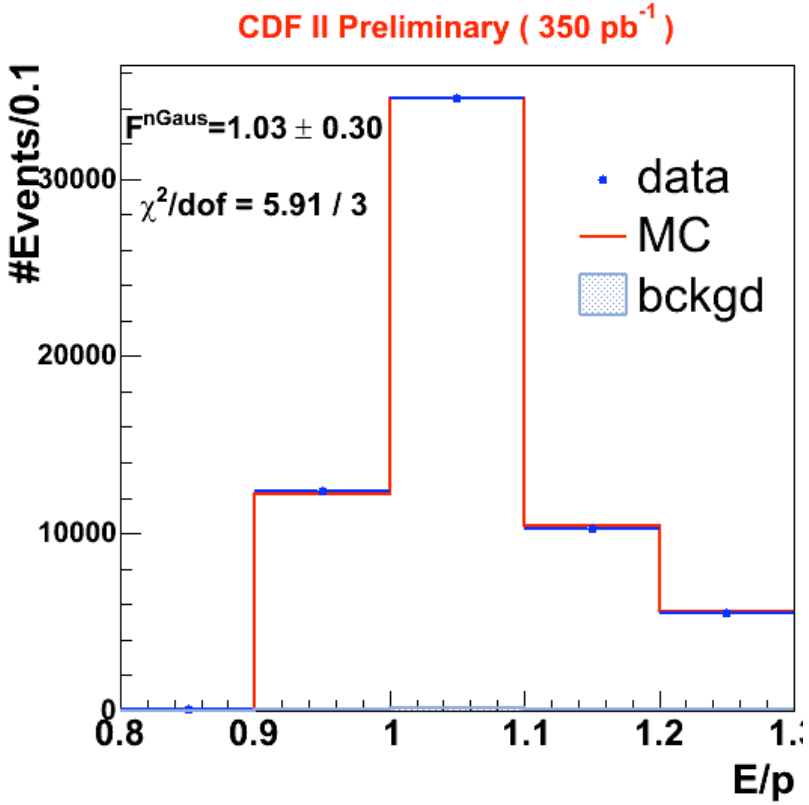
Γw

- the high m_T tail contains information on the W boson width

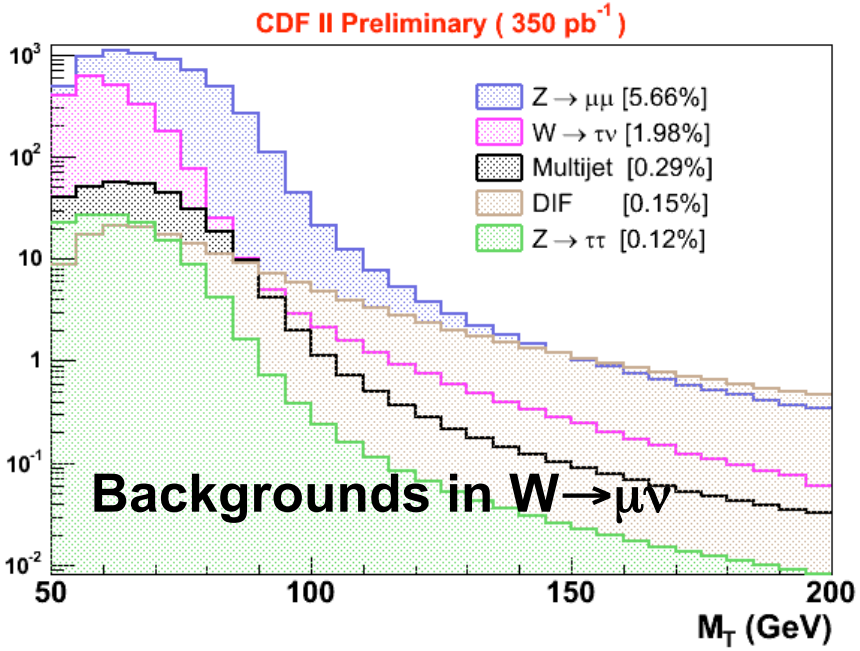


Understanding of resolutions & backgrounds critical

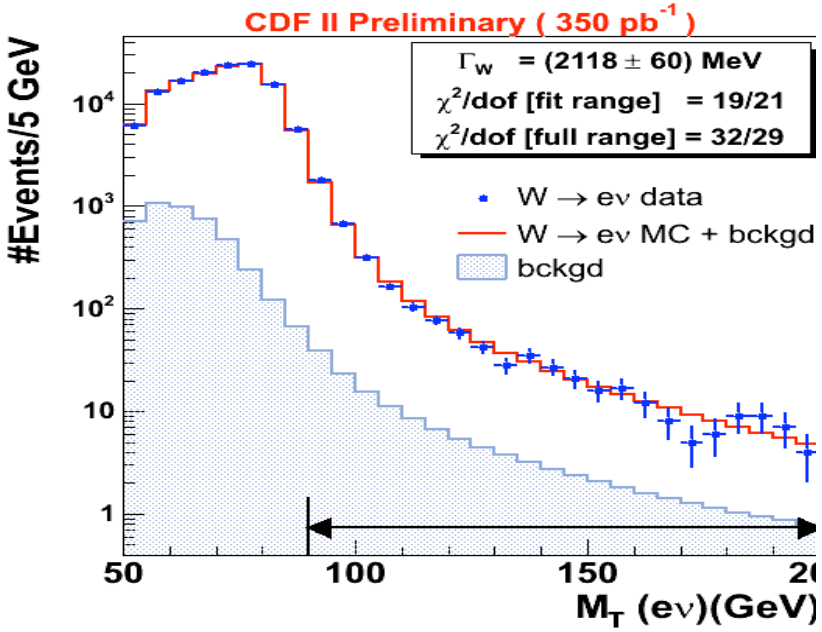
Γw

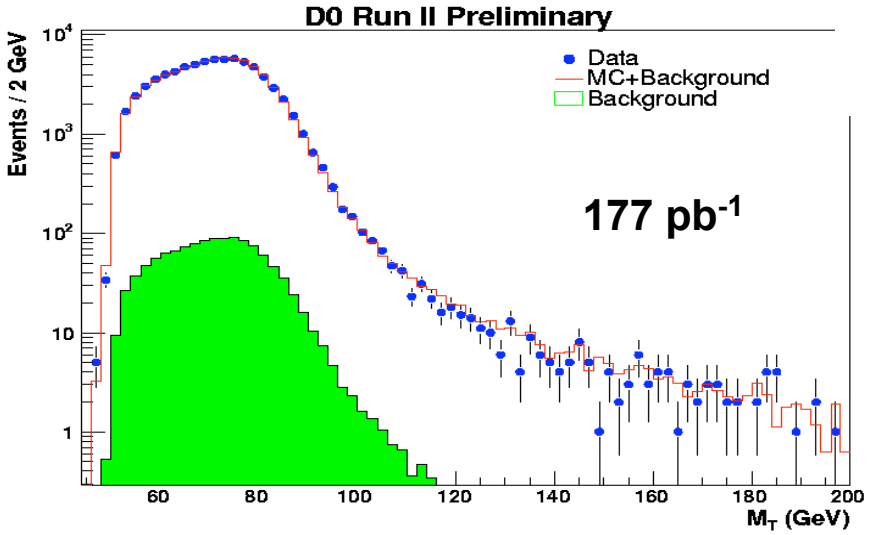


constrain non-gaussian tails in tracking resolution from E/p



Γw





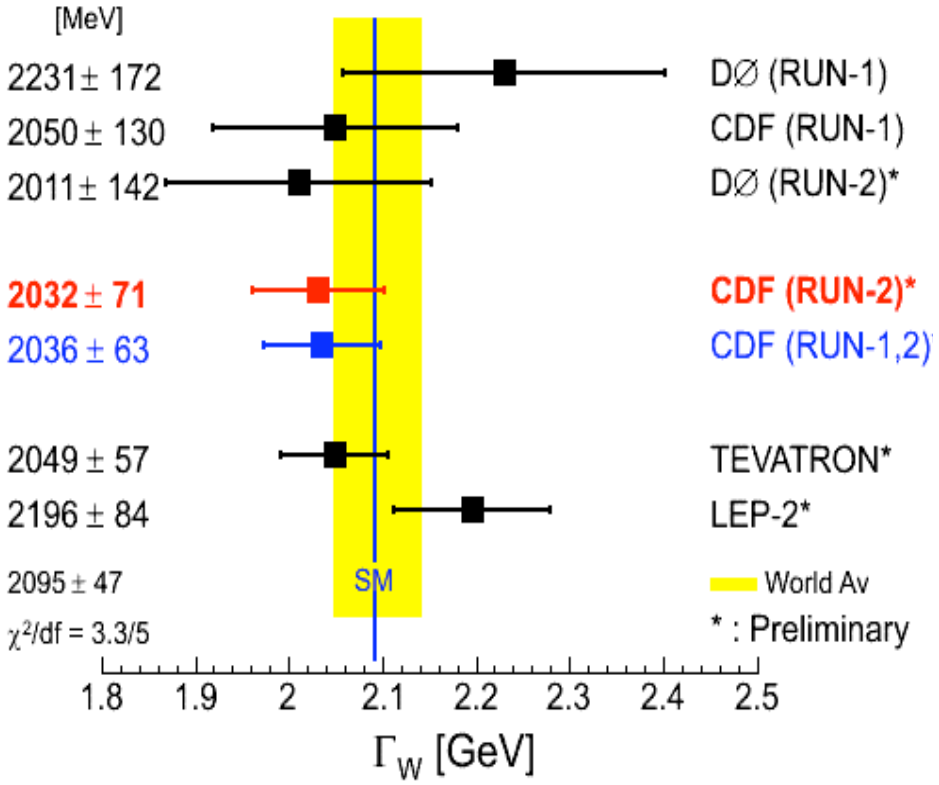
CDF Run II Preliminary (350 pb^{-1})

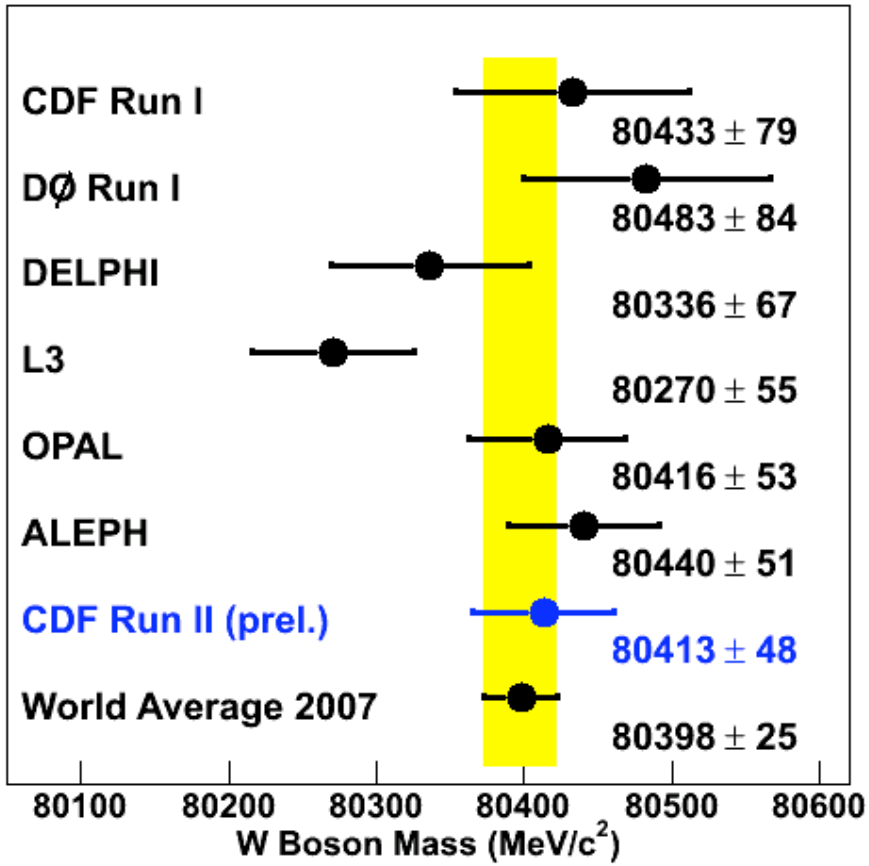
	$\Delta\Gamma_W$ [MeV]		
	Electrons	Muons	Common
Lepton Scale	21	17	12
Lepton Resolution	31	26	0
Simulation	13	0	0
Recoil	54	49	0
Lepton ID	10	7	0
Backgrounds	32	33	0
p_T(W)	7	7	7
PDF	16	17	16
QED	8	1	1
W mass	9	9	9
Total systematic	78	70	23
Statistical	60	67	0
Total	98	97	23

ΔΓw [CDF(e+μ)] = 71 MeV

ΔΓw [DØ (e)] = 142 MeV

World Averages



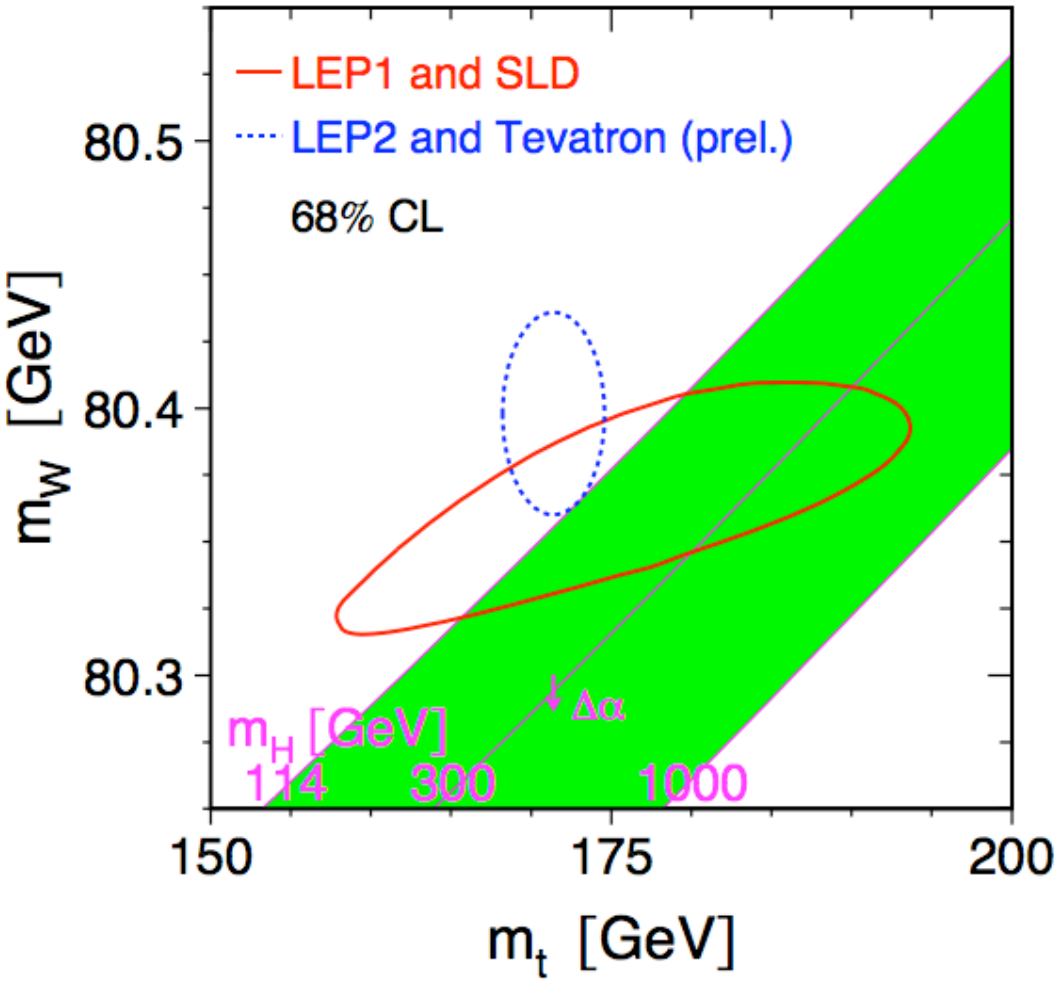


CDF now has most precise single experiment measurements of the W boson mass and width

Reducing world average uncertainty from 33→25 MeV

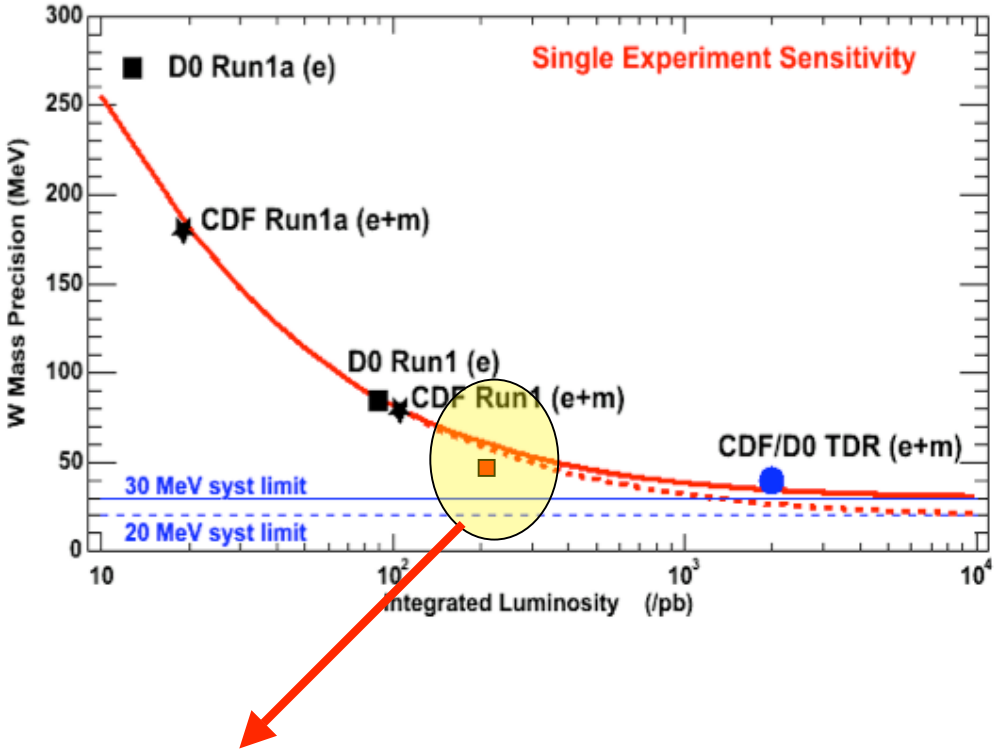
Impact on Higgs

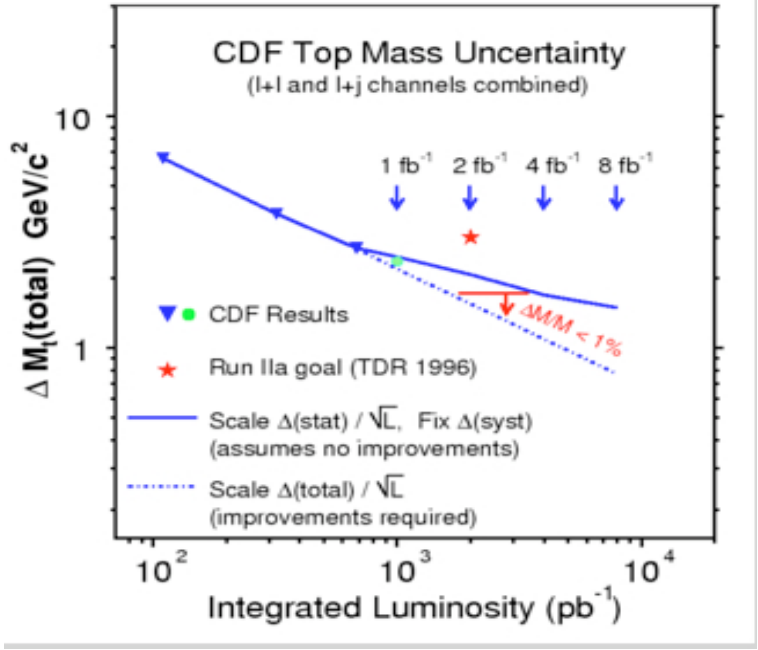
M_h < 142 GeV at 95% CL (cf 166 GeV at ICHEP 2006)



Future Prospects

- from a year ago





Beware extrapolations - for M_W & M_t Tevatron has done better than expected.

1 GeV is possible for top mass and 20-25 MeV for W mass

These measurements could pin down the SM Higgs beautifully or rule it out !

Conclusions

- We've now seen all expected SM EWK processes except ZZ, single top and the Higgs

-The precision of many of these measurements is now surpassing LEP e.g. ZZγ TGC, Mw, Γw & will continue to improve as datasets grow by up to a factor of 10.

- Valuable constraints within SM e.g. PDFs and NNLO QCD will come with final datasets.

- Future prospects are bright for removing the wriggle room of the Higgs from ~ 25 MeV W mass measurement.

Backup

BFKL Effect on Z p_T

- LHC data on this will be very interesting